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DISPLAY SIZE: A LITERATURE SURVEY AND A STUDY WITH SLR IMAGERY (U)

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FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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A literature survey of studies relevant to display size is followed by discussions of display size geometry, size calculation equations and selection of display size for imaging displays. A display size study was done. Display size was varied by using small (5" X 5"), medium (10" X 10") and large (15" X 15") film transparencies of side-looking airborne radar (SLAR) pictures viewed on a light table. The targets, one per picture, were 12 airfields, 12 railroad yards, and 12 tank farms. All targets were adequate in size for easy visual examination. The observers were 72 SAC and TAC radar navigators. The only briefing information for each picture was the type of target to be detected. Each observer saw each scene only once. Target detection time was measured.

No target was difficult for all observers, but some were difficult for some. Average response times on individual scenes were sometimes quickest on the small display,
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and sometimes quickest for the medium or large display. Airfield and railroad yards were found quickest on the small display, the size for which response to tank farms was slowest. The results demonstrate that, when sensor and display resolutions and target image size are adequate, the display size yielding the quickest target detection for unbriefed targets depends upon the type of target. Keywords:

SUMMARY

The physical size of an imaging display is a factor in determining its suitability. Display size impacts both the performance of the observer-display system and total equipment cost. Size influences the ease, rapidity and accuracy of information extraction. Many research studies have used display size as a factor or variable. However, no single source in the scientific literature adequately covers the published research relevant to the selection of display size. Available research reviews often give little or no details on important aspects of the research papers that they discuss. Some valuable research is not readily available. The present paper reviews research literature, both that which is readily available and some that is not. The review section is followed by a section on selecting a display size and a section on display size geometry that derives some of the display size algebraic formulas found in the literature. Finally, some research by the author that has some interesting results is reported. This research examined detection and recognition of unbriefed targets on static side-looking radar pictures of different sizes but with identical terrain coverage. Three sizes of pictures covered a size range from small to large.

PREFACE

This report was prepared in the Human Engineering Division of the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed under Project 7184, "Man-Machine Integration Technology," Task 718411, "Design Parameters for Visually-Coupled and Visual Display Systems." Special thanks are due to the Strategic and Tactical Air Commands for supplying officers to serve as test subjects. Thanks are due to Mr. Don F. McKechnie for training the experimental subjects to recognize targets on side-looking radar displays. Thanks are due to Miss Tanya Ellifritt and to Miss Yolanda Crawford for help in preparing the manuscript.

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SECTION I

DESCRIBING DISPLAY SIZE

The size of a visual display is usually described in terms of linear size, angular size or viewing ratio. Linear size is the length of display dimensions, such as display height, width, diagonal, or diameter. Angular display size is the size of the angles subtended at the observer's eye by the physical dimensions, and is usually given in degrees. Angular size varies with both linear display size and viewing distance. Thus, angular size is a measure of a relationship in a situation rather the size of an object or image. Viewing ratio is the ratio of viewing distance to display height, so that it is also a measure of a relationship. Viewing ratio is sometimes used in television research.

These three display size measures may be illustrated with a 21-inch diagonal television screen that is 16.6 inches wide and 12.6 inches high. Let it be viewed from a distance of 10 feet along a line perpendicular to the screen and passing through its center. Here, linear display size is a 21-inch diagonal with a 4:3 aspect ratio (16.6/12.6 = 4:3). Angular display size is a 10-degree diagonal (2 Arc Tan (21/2)/(10 x 12) = 10^{o}). Viewing ratio is 7.1:1 (10 x 12/16.8 = 7.1).

A visual display user focusses an image of the display upon the retina at the back of the eye, where visual receptors or sensors are located. The linear sizes of the retinal image and of the elements making up the image are determined by the angular size of the display and its elements, which, in turn, depend upon display linear size and distance from the observer.

Thus, viewing a small but close display may yield the same angular display size and linear size of retinal image as a larger but more distant display. The display observer may be aware of the linear size of the display, but it is angular size , hence retinal image size that is important in perceiving display contents.

When a CRT or other image source is examined by looking into an optical device such as a magnifier or a telescope, the image presented to the optics of the eye is a virtual image that is often located at a large optical distance from the eye. The optics of the eye focusses this virtual image, which is the display, to form a real image on the retina. Virtual images may be located at optical infinity, i.e., be collimated. Aircraft head-up displays and helmet-mounted displays are usually collimated. The image being infinitely distant, all physical display lengths (width, etc.) are of infinite linear extent, hence of no value in describing display size or relating observer performance and display size. However, the angular display size in contrast to the linear size is finite, as is the size of the display image on the retina. Thus, the angular size of collimated displays and of virtual image displays at any optical distances is meangingful and useful in describing display size. When comparing or combining results obtained with displays of different sizes at different distances, angular display size rather than linear or physical size is required.

VARIABLES IMPACTING DISPLAY SIZE SELECTION

There are usually constraints limiting display size for system use, for example, the necessity in an aircraft cockpit of providing sufficient space for safe pilot ejection, and the presence of a crowded instrument panel that has no space available for a large display. In addition to space constraints, many other factors must also be considered so that display size selection may be a complex task. These factors, variables or characteristics may be grouped or classified according to several different schemes. One technique is to classify variables as environmental, sensor and signal processing, display, operation or mission and task, and observer factors. A complete listing of variables, whatever the scheme for classifying them, would be encyclopedic. However, a few of them will be mentioned to illustrate the complexity of the display size selection process.

Environmental factors include the terrain and target, the atmosphere, electromagnetic interference, vibration and buffeting, etc. Each factor, for example target, covers several variables. The sensor variable includes sensitivity over the range of frequencies covered, signal-to-noise (S/N) ratio, dynamic range, modulation transfer function (MTF) at various locations in and directions across the field of view, etc. Display factors include dynamic range as measured by, for example, shades of gray, display S/N ratio, the number of resolved elements at various locations in various directions across the display, and similarly for MTF at various display locations, scan line or raster visibility, available display luminance and contrast, display gamma, viewing distance, etc. Some of these items are clearly overlapping measures of characteristics.

Operation or mission factors include the overall mission, amount of time available to obtain required information from the display, the type and amount of information that must be extracted, the accuracy required in target identification and position designation for weapon delivery, briefing or a priori target information, contextual cues to target location, additional tasks and duties, such as tracking, navigation, monitoring instruments, lookout for other vehicles, etc.

Yet another set of variables, factors or characteristics pertain to the human who examines the display. These are observer, user or operator variables, and, unless they are allowed for in designing the display, the most sophisticated sensors and signal processors may be of little value. The display must be tailored to fit the user and the mission or task. User or observer variables are numerous and vary greatly in magnitude from one person to another. Often they are not simple or easy to assess and specify and often strongly interact. In addition, they are not constant, varying from day to day and with mission events and duration. Of primary importance are those variables pertaining to how well the observer can discern the fine details on the display, his visual resolution. There are various types of visual resolution: minimum separable, minimum detectable or spot, and alignment or vernier. Measures of visual resolution include Snellen letter acuity, grid or checkerboard resolution, MTF, contrast sensitivity, etc. The observer's visual resolution, MTF and contrast sensitivity vary with location on the retina of the eye, i.e., in the field of view of the eye, orientation of the test pattern, display luminance, the ratio of display luminance to surround luminance, wavelength and wavelength distribution, contrast, S/N ratio, stimulus duration, object or target shape, flicker, observer luminance and chrominance adaptation level, accommodation (eye focus distance), accommodation error, observer and display vibration, partial oxygen pressure, etc. In addition to visual capability, account must be taken of search strategy, attention and vigilance, visual reaction time, speed of eye movements, motivation, training and experience, task loading from non-display related tasks, etc.

Observer characteristics are often largely ignored when selecting display size. Because of space constraints, it is commonplace to find displays that are too small to impart adequate details of the target. As noted earlier, displays may be quite far from the eye to allow safe pilot ejection, so that fine details are not visible. Years ago Biberman (1971) noted that many existing and planned airborne systems had displays that demanded 4 to 10 times more visual acuity than observers had, and that to obtain the maximum amount of information from such displays would require a magnifier of 4 to 10 power. He stated that "more of the early airborne systems were deficient because of inadequate display size than for almost any other reason." It is pointless to present details that can't be discerned. When sensor resolution cannot be preserved in the display, and an adequate display is not feasible, then a far less expensive sensor system would serve just as well. It is to be hoped that, in recent years, fewer systems have displays departing so far from optimum or even necessary minimum size as those that were examined by Biberman.

At the risk of being repetitious, it will be said once more that the visual capabilities of the observer, the nature of the task or mission and the manner in which sensor information is displayed all influence the rapidity, accuracy and completeness with which necessary information is obtained from the display. The size of a display can be critical in extracting the information on display, and a display can be too large or too small for maximum efficiency.

SECTION II

SURVEY OF THE LITERATURE PERTINENT TO THE SELECTION OF DISPLAY SIZE FOR IMAGING DISPLAYS

A. PRELIMINARY REMARKS

The primary interest of this survey, and the research study that follows it, is with pictorial displays for use by a single observer. Group displays are not examined. Pictorial displays exhibit pictures: television, side-looking airborne radar (SLAR), forward-looking infrared (FLIR), etc. For this reason, the numerous studies that have been done on symbol size and resolution will not be reviewed. Shurtleff (1967) reviewed the literature on television legibility, and would be a good starting point for those interested in symbol size and resolution. Meister and Sullivan (1969), as part of their "Guide to Human Engineering Design for Visual Displays", reviewed several studies on symbols and are also a good starting point or a source of data. It is of interest to note that Meister and Sullivan conclude that symbol resolution should be a minimum of 10 TV lines and that symbols should subtend a minimum of 12-15 minutes of arl at the observer's eye. These values are not much different from those that have been obtained from studies on target image sizes and resolutions using pictorial imagery, as will be illustrated by the studies discussed later in this report. It is of some interest to see what a current military standard has to say on this topic. Military standard - 1472C (1981) states: "When a target of complex shape is to be distinguished from a nontarget of complex shape that is also complex, the target signal should subtend not less than 6 MRAD (20 arc minutes) of visual angle and should subtend not less than 10 lines or resolution elements". The 10 TV lines resolution here agrees with the 10 lines for symbols noted above, while the 20 minutes of arc for nonsymbols exceeds the 12-15 recommended for symbols. Displayed symbols are usually greatly overlearned, and are usually all of the same fixed size and orientation on the display, do not move, and do not compete with noise or clutter. The difference in recommendations, considering these points, is in the expected direction and appears reasonable.

There is a very extensive literature on research relevant to the selection of display size. Only a sample of this material can be included in this review. Some research is covered because of its historical interest and significance. Some of the studies are classics. Some of the research is included because, while pertinent, it is not readily available to most readers. The bulk of the studies were included because they were pertinent and important. In addition to excluding most studies using symbols, studies using PPI (Planned Position Indicator) scopes with target blips were also largely ignored. Several studies of some interest were excluded because results could not be generalized to other situations or readily related to resolution lines-over-target, or are largely obsolete because of later and more useful or relevant research. However, exclusion from this review of studies does not mean that the methods or the results were not satisfactory, or even that they were not exemplary. Not all studies could be included.

Several literature reviews and collections were examined in preparing the present one and, in general, they tended to give few details on individual studies, making it difficult for the reader to decide how generalizable the results might be or how applicable they might be to his own problems. The present review discusses some research in considerable detail to alleviate this problem and to illustrate the complexity of research pertinent to display size. Some studies are not discussed in detail. The choice of which to discuss in detail and which to give only abbreviated coverage is based in part on their significance or interest, but also reflects the interests and biases of the reviewer.

The studies covered in the review are presented largely in their historical order, rather than by topic categories. This was done, in part, because several studies include multiple topics or variables. Although this procedure makes for less cohesion, it preserves historical perspective while avoiding repeated references to some studies.

Some of the reviewed research directly address display size. Others examine variables that impact display size selection, such as resolution, target image size, sensor angle of view, terrain coverage and display viewing distance. The range of research covered is quite broad, and includes various targets and target backgrounds, sensors, displays, resolutions, signal-to-noise (S/N) ratios, shades of gray, image motion rates, briefing levels, missions and tasks, training, instructions, observers, etc.

B. LITERATURE REVIEW

Bartlett et al. (1949) investigated the visibility of a radar pip as affected by its length and width. The pip on a Plan Position Indicator (PPI) display is an arc segment, a fading patch of light on a fading background. A standard radar viewing screen of the PPI type was used with simulated radar echoes. Subjects were well trained. Viewing distance was 12 inches and the room was very dim. A wide range of beam widths and pulse lengths were used with the method of average error, an adjustment method of measurement. Thresholds were measured for fixed PIP sizes at three brightness levels. Visibility increased with beam width and pulse length, rate of increase depending upon background brightness. PIP visibility was shown to be given by the formula Visibility = V = A Log (beam width) + C Log (pulse width) + d = A Log (PIP area) + C. Results were summarized in tables, graphs, and equations.

Williams et al. (1955, 1956) used blips on a Plan Position Indicator (PPI) type of display to examine target detection thresholds. They found that, with blips on a clear background, observer performance improved as the size of the CRT increased from 5 inches up to about 21 inches. However, CRT size became less important as blip size increased from 2 to 16 mm in diameter. For larger blips, medium and small CRT displays were as efficient as large displays. In operational radar the blips will be small, so that the larger the display, up to about 21 inches, the better the detection. However, once blip sizes are adequate, larger scopes increase the area of display that must be searched, reducing detectability.

Jesty (1958) examined the relationship between CRT resolution, picture size, and preferred viewing distance. The television system used was a monochrome closed-circuit TV with eight experimental conditions made up from combinations of 405 and 625 TV lines with a 2:1 interface and bandwidths, obtained with fully-corrected low-pass filters, of 7, 3, 1.5, .75 mHZ. Subjects were told to move their chairs to where they would most like to view the pictures. With higher resolutions, subjects preferred closer viewing distances, i.e., they sat closer to displays that had sharper pictures. Using a spot-wobble technique on the TV scanning beam to make TV raster lines less conspicuous, earlier work of other researchers was confirmed that spot-wobble improves picture quality. Using projected color transparencies of varied sharpness obtained by defocusing yielded results similar to those with the TV tests: closer preferred viewing distance for sharper pictures. By varying screen luminance from 5 to 50 ft lamberts, it was found that luminance has only a second-order effect on apparent picture sharpness, as measured by viewing distance divided by picture height, V/H. The optical experiments with the projector showed that viewers behaved, in terms of preferred viewing distance, as though reacting entirely to picture sharpness, ignoring perspective in the pictures. Although Jesty's study showed the importance of TV line number on preferred viewing distance, it did not, as Jesty notes, determine optimum viewing distance for information extraction as a function of TV characteristics.

An interesting point that is often not considered in selecting display size is that the best efficiency in searching for targets depends upon the angular size of the display. However, a display may be very efficient, in terms of eye movements and fixations, and yet be of little use to an observer because target images are too small and because terrain coverage is too small so that the target is on display too short a time, if on the display at all, etc. Search efficiency is but one of many factors to consider when selecting display size. Also, the size of display yielding the most efficient search on a static image display may well not be the size for best search efficiency, as defined by eye movements and fixations, with moving or dynamic imagery. Keep in mind that eye movements, no matter how efficient in terms of where one looks on the display, won't help if target images are too small, terrain coverage is inadequate, etc. Thus, search efficiency is but one of many factors to consider when selecting a display size.

Enoch (1960) defined target search efficiency as the percentage of eye fixations falling within the display area. He performed a static image display study that found a decrease in search efficiency with display angular sizes less than 9^{o} in subtended diameter. In his study 12 untrained students and university employees viewed a series of 9" X 9" experimental maps. The display size was varied from small to large by circular masks placed on the pictures. The display sizes, in terms of the angle subtended by the picture diameter at the observer's eye, were 3^{o}, 6^{o}, 9^{o}, 18^{o}, and 36^{o}. A modified opthalmograph recorded observer's eye traces, showing where they were looking on the maps. The target was a Landolt "C". Note that the image scale and the size of the target image did not vary with changes in the size of the display, while terrain coverage did vary. Note also that still pictures were used. He found that display coverage by the eyes was not uniform. Greatest attention (most fixations) was paid to the center of the display. Border areas were generally avoided, although actual borders were not avoided. The upper left corner of the display was consistently avoided. The right hand side and the bottom of the display were favored. There was greater concentration upon details in smaller displays.

Search behavior was essentially the same for displays subtending 9^{o} or more at the observer's eye. As display size became smaller than 9^{o}, the average duration of eye fixations increased, interfixation distance decreased, there was increased concentration of attention to the center of the display, and search efficiency markedly decreased. Keep in mind that here search efficiency, as noted earlier, means percentage of eye fixations falling within the display.

Enoch concluded that the optimum static display would subtend 9^{o} at the observer's eye. In displays smaller than 9^{o} too many eye fixations fall outside of the display. In displays larger than 9^{o}, nonuniformity of eye fixations on the display causes a drop in observer performance. The data of this study could be interpreted to mean that the display angular subtense should be 9^{o} or larger, rather than just 9^{o}. As a point of interest, a 9^{o} subtense at a viewing distance of 28 inches corresponds to a 4.4 inch display, which is quite small. In an air-to-ground display (which is not static), very narrow angles of sensor field-of-view would result and images would be on the display for only a very short time when not tracked by the sensor.

An aspect of Enoch's study that limits its generality is the artificial target, the broken ring or "C" which is easily recognizable when examined. Other objects are not likely to be mistaken for it. As mentioned, his data could be interpreted to indicate that a display in a search situation should not be smaller than 9^{o}, rather than be 9^{o}, since observer performance was essentially the same for 9^{o}, 18^{o}, and 36^{o}. Also, when image scale is adequate in an airborne display, unless target locations are known and the sensor is accurately aimed, a small display may not include many, or even any, targets. They may not be in the field of view of the sensor.

Since Enoch's scenes were static, i.e., did not move or change, generalization to dynamic displays is difficult. Also, since the varied amount of terrain on display while holding image scale and target image size constant, generality of findings are further reduced. More meaningful for many system designers would be results obtained from dynamic displays with terrain coverage held constant while image scale and displayed target image size varied with display size. Also, system performance measures of percentage of targets detected, detection time, percentage of errors, etc. would be more useful as measures in determining optimum display size than would distributions of eye fixations.

Steedman and Baker (1960) examined the speed and accuracy of form recognition for a range of target image sizes, measured in terms of angular subtense at the observer's eye, with various amounts of detail resolution in a field of low clutter. Targets were random forms generated on a statistical basis by filling in with black some of the white cells in a large (90,000) cell matrix. The subject's task was to find, on a display containing many random forms, the form matching a briefing form shown prior to the display presentation. They found that both search time and errors did not vary until the visual angle subtended at the observer's eye by the target fell below 12 minutes of arc. Below 12 minutes, performance deteriorated: errors were frequent and detection times were long. This finding held for all resolutions investigated. The authors concluded that the target image on a display must have a minimum angular subtense of 12 arc minutes for relatively accurate and rapid recognition. The author notes that: (1) the briefing target was an exact replica in size and shape to the target image, i.e., target intelligence was perfect; (2) the target was always present; and (3) the target was always of high contrast and viewed under ideal conditions. From these considerations and noting the artificiality of their simulation, they concluded that in an operational environment the minimum of 12 arc minutes may be unrealistically small, and that, where practical, the minimum visual angle of a target image on a display should probably be approximately 20 arc minutes rather than the 12 minutes that they found. Miller and Ludveigh (1960) also worked with artificial targets on a homogeneious ganzfeld. They also found that speed and accuracy in search and identification had similar requirements for the angular subtense of targets. Both studies found that this angular requirement held over a range of target image resolutions. A third artificial target study was reported in the same year by Boynton (1960). He varied viewing distance and target size. Target contrast varied form 44 to 100 percent. Targets were recognized approximately 60% of the time when angular subtense at the observer's eye was 10 minutes of arc. When angular subtense was 20 minutes, recognition percentage jumped up to 87%, a large increase.

Smith (1962) discusses the problem of "why large displays"? He says that interest in large displays is mainly attributable to historical deficiencies in display technology. Specifically, certain types of air defense displays were once generated by humans with grease pencils who did manual plotting, so that displays had to be large. Also, for the same reason, usually only one display could practically be generated and maintained. He notes that, from the standpoint of visual geometry, when one has a display area in the solid angle in which all of the area can be covered by eye movement alone, large and small displays are equivalent. A small display close up is equivalent to a large one farther away. He concludes that, under optimal viewing conditions, large displays and small displays present equivalent amounts of information.

A study of some interest, although it does not contain test data, was done by Whitham (1965). It consists of a series of design charts relating display element size, overall display size, viewing distance, and maximum symbol quantity. The charts are based on bright displays (photopic vision) and observers with a visual acuity limit of one minute of arc. However, if displays are to be used in aircraft, it is more realistic to assume, as noted earlier, that observers will have an effective visual acuity of 2-3 minutes of arc.

Evans, Levy, and Ornstein (1965) used motion picture images of a TV monitor projected onto a beaded screen. The TV camera was moved over a 3,000:1 scale terrain model, looking straight down, simulating 1,500 feet/second at 12,000 feet and traversing a 10 nautical mile path that was 4,500 feet wide. The camera showed 1,000 feet of terrain along the path. The TV monitor had a 440 line resolution. Targets were an aircraft, a small building, and a tank farm, all three being undetailed silhouettes. Target location on the terrain was systematically varied. Display size (really, angular subtense) was varied by using 3, 6, and 12 foot viewing distances from the display screen. Observers were 60 male college students. Overall, viewing distance had no statistically significant effect on probability of detection. Since varying viewing distance simulated varying display size, it may be concluded that the various display sizes were equally effective for the detection of the silhouette targets.

Although he does not review studies on display size, Carel (1965) devotes 3 pages to display size. Despite its 1965 date, his report appears to still be one of the best documents on pictorial displays for flight. It includes consideration of several factors impacting upon display size, such as image scales, field of view, resolution, TV field rates, etc.

Simon (1965) varied display size and field of view in a target recognition study. He compared recognition probability, P, on 6" and 12" displays of simulated radar imagery. The image scales that he used were 54,000:1 and 108,000:1 for the 12" display, and 108,000:1 and 216,000:1 for the 6" display. Viewing times for the radar observers were 10, 20, and 40 seconds. When fields of view (terrain coverage) were the same for both displays, P was almost identical when the image scale was 54,000:1 for the 12" display, P was higher at a scale of 1:54,000 than for a scale of 108,000:1 and, for the 6", P was higher at 108,000:1 than at 216,000:1. With narrower fields of view, then, and the consequently larger target images and reduced amount of terrain to search, target recognition probability was higher for both displays. Simon's results may be summed up by noting that, for the imagery that he used, longer viewing times were better with displays of both sizes, narrower fields of view were better, and, when terrain coverage was equal, the 12" display was equal to the 6" display at one image scale and slightly better at another.

Semple (1971), discussing display size, noted that the high resolution radar study of Simon (1965) did not take into account the fact that image scale factor was varied when display size and sensor field of view were varied. Replotting Simon's data, he concluded that display size, image scale factor and viewing time all strongly influenced detection probability. It was apparent that the 12" display should yield about the same performance for target detection as the 6" display. Semple concludes that the effects upon target detection probability of display size are fundamentally similar for PPI and imagery presentations, and that smaller displays yield higher target detection probabilities.

Rusis and Snyder (1965) examined the effect of TV camera field of view and target size upon air-to-ground target recognition. Stimulus material was collected at 5 pictures per second on 35 mm photographic film from an aircraft flying at 165 knots at an altitude of 500 feet in daylight. The field of view was 53° horizontal and 40° vertical. The film was printed on 16 mm film and projected upon a rear-projection screen, which was viewed by a closed-circuit TV camera. Lens changes on the TV camera varied how much of the scene was viewed, yielding 3 fields of view: 25° vertical X 34° horizontal, 7.5° X 10°, and 6.2° X 8.2°. In each case, the field of view filled the screen of an 8-inch TV monitor viewed in real time by subjects inside of a booth simulating an aircraft cockpit. Simulated aircraft speed was 198 knots. The targets to be found by subjects were of 15 types, including boats, houses, road, factory, etc. Sizes on the display at a 1,060-foot simulated aircraft distance was used to divide targets into 8 large and 7 small targets for scoring purposes.

The subjects were 30 male college students, all with at least 20/20 static near visual acuity. They had oblique photographs of each target as briefing material for study before tests and use during test runs. Their task was to find and designate, with a pointer, each target when it was as far away from them as possible, but to do so as accurately as possible. Ten subjects were randomly assigned to each field of view. The percent of targets recognized increased as the field of view increased (p .01), and the 8 largest targets were recognized more often than the 7 small targets (p .01). The average range of targets when recognized increased as the field of view decreased (p .01). Recognition errors did not differ significantly with different fields of view, but were more frequent for the small targets (p .01). In summary, bigger targets were more likely to be found, and, on average, were found at longer ranges and with fewer incorrect recognitions. Also, average recognition range was greater for narrower fields of view, even though recognition probability was less.

Oatman (1965 a, b, c) examined target detection at horizontal resolutions of 300, 400, and 800 TV resolution lines. Target detection probability increased significantly between 300 and 400 lines, but did not further increase significantly in going to 800 lines.

Brainard, Hanford, and Marshall (1965) had observers view a TV monitor displaying a terrain board as seen by a moving closed circuit TV (CCTV) camera mounted on a boom. The system simulated overflight by an aircraft with a TV display in the cockpit. The approach to the target was a computer-controlled ramp flight path inclined down 15° from horizontal. The simulated aircraft speed was 500 feet/second. Runs started at an altitude of 5,800 feet at a point 22,500 feet from the target. The CCTV had a bandwidth of 8 MHZ and a S/N ratio of approximately 35 decibels, providing good quality images. The task of the observers, 10 company employees, was to identify, as quickly as possible, which one of 5 targets was present in a small inscribed area on the terrain board. The 5 targets were: oil storage tanks, an aircraft, a bridge, and two buildings. No search was necessary and a target was always present. Observers had, prior to and during each target run, reference photographs to examine and study. Even so, the author stated that, in the absence of contextual cues, the task was not an easy one.

For each of 5 targets, identification accuracy increased approximately linearly with the number of TV scan lines traversing the target, except at high identification probabilities, where the increase rate fell off, i.e., the curve was negatively accelerated. To attain a .9 probability of correct identification, the building required approximately 10 TV lines of resolution across the target, and the bridge required about 7-8, the other three targets falling between bridges and buildings in number of required resolution lines. The main results of the study, then, was that identification requires 8 or more TV lines under the conditions of the study, and that at lower probabilities of correct recognition, probability of correct identification was approximately linear with number of lines through the target.

Although Brainard et al. (1965) does not say so, it appears quite likely that more lines across the target would have been required had target search been required, or if more types of target had to be discriminated, or if targets had been more similar to each other, or if targets were not always present, or if nontarget objets were sometimes present, or if there were no reference photographs to compare to the target image on the display. In operational situations, then, it appears likely, from this study, that over ten, maybe considerably over ten, lines would be required.

Bate and Porterfield (1966) used a display height of 18 inches with display widths of 4.5, 9, 18, and 36 inches. Imagery in the form of a continuous strip of terrain as seen by a high resolution side-looking radar moved from left to right across a rear projection display. Image motion rate simulated an aircraft speed of 1316 knots. Image scale, and hence displayed target image size, was constant for all display sizes on display at any one time: terrain coverage varied with display size. Targets were targets of opportunity, i.e., were unbriefed. Increasing screen width, hence instantaneous terrain coverage, and the amount of time that targets remained on the display, had no effect upon either the percentage of targets detected or the number of nontargets mistaken for targets. However, response time to targets increased linearly with display width. More time was available per target, hence this result is not surprising.

Erickson and Main (1966) used real targets on real terrain that was cluttered or complex. The targets were a tank, a truck, a jeep, an artillery gun, an armored troop carrier and a radar van. Imagery came from 35-mm color motion picture film taken from the nose camera of an A-4 aircraft at 2,000 feet above the terrain. The color film was projected onto a screen where it was viewed by a monochrome camera and recorded on video tape. Scene image scales, target sizes, aspect angles and lighting were varied. In addition to real image tests, tests were conducted with abstract symbols as targets. Subjects were 10 senior high school boys who received familiarization training. Abstract symbols could be located 90% of the time with 10 TV lines across them, and identified 80% of the time with 10 TV lines. However, real targets on real cluttered backgrounds could be located (detected) every time with 6 TV scan lines across them, but identification with certainty required over 20 scan lines. With 20 lines, about 83% of the targets were correctly identified.

Bennett et al. (1967) extensively researched rapid target recognition by well-trained subjects. Stimulus material was aerial photography from a

KC-1 aerial camera of eight types of targets: airfields, nuclear storage areas, barges, fighter aircraft, industry, towers, antennas and trucks not on roads. The displayed picture size was 7.3 X 7.3 inches. Image scales were 1:2,000, 1:10,000, and 1:15,000, with the middle scale picture covering one nautical mile of terrain. Levels of contrast, resolution and photographic granularity were used that covered, according to the authors, the practical range of sensor variation. Quality parameters were independently varied. Contrast (Gamma) covered levels of low (.36), medium (1.0) and high (3.0). Resolution levels, varied by spacing in making contact points, were: no deresolution (about 40 line pairs/mm), slight deresolution (20% of original), medium deresolution (5% of original) and marked deresolution (2% of original). Granularity masks used in contact printing produced no (really, negligible) grain, slight (.004"), medium (.009"), and marked (.002 inch average grain size) granularity. Marked grain was chosen to approximate side-looking radar imagery. There were 24 photographs, each containing from 1 to 28 targets.

Subjects were 24 IBM engineering personnel without previous training. All were given extensive training of 10-12 hours per person which included both undegraded and degraded photographs of all target types at all image scales. A confounded experimental design was used, with each subject viewing 16 of the 24 scenes. For each picture the subject was told that a target of a specified type would appear and that he was also to look for other targets. Recognition probability or completeness was number of targets correctly responded to divided by the number present. Response correctness (accuracy) was total number correct divided by total number or responses. Effectiveness was defined as the product of completeness and accuracy. Subjects were allowed ample time.

By statistical test, the main effects of briefing, targets, granularity and resolution were significant. Image scale and contrast effects were not significant, both apparently being in a usable range of values. Knowing that a target of a specified type was present significantly increased completeness by a factor of more than 3. There was a definite interaction between resolution and target type, and between resolution and image scale, making it difficult to generalize about resolutions. Observer performance was poorer when one line of resolution was spread out over more than three arc minutes of angular subtense, illustrating the harm from overmagnification.

The importance of this study, only a few of whose many results are mentioned above, is its variation of numerous variables. This made it possible to demonstrate the interaction of resolution with other variables and to demonstrate the harm of overmagnification for the available resolution.

Hollanda, Scott, and Harabedian (1967) examined the information value of noiseless, static, line-scan images. Accurate scale models of 25 different military vehicles were photographed both obliquely and from straight overhead (vertical): 10 tanks, 5 support vehicles, 5 self-propelled guns, and 5 trucks. Each photographic transparency was converted by a line scan generator, using electronic, optical, and mechanical means, into a line-scan photographic film transparency to be directly examined by observers. There were six values of number of line scans per vehicle: 4, 6, 9, 13.5, 20, and 30. Twenty-four subjects who were not trained photo interpreters were tested with the oblique pictures and another similar group of 24 were tested with the oblique pictures and another similar group of 24 were tested with the vertical pictures. The task was to match each target image on the picture with the appropriate scale model. Subjects had minutes per test, so there was no hurry.

Percent correct identifications ranged from 5 to 35 at 4 scans/vehicle, to 90-100% at 30 scans/vehicle. The percentage of correct classifications ranged from 20-50% at 4 scans to about 100% at 30 line scans per vehicle. Performance at 20 scans/vehicle was clearly superior to that at 13.5 scans. The authors concluded that approximately 20 line scans per vehicle is a minimum acceptable number, in most cases, for satisfactory results.

Humes et al. (1968), in a quite comprehensive study of display factors for low-light-level TV (L^3TV), examined the effects of signal-to-noise level ratio (S/N) and TV scan lines-over-target for moving scenes with a TV camera pointing forward and downward. S/N ratios used were 1.1:1, 2.1:1, 6.5:1 and 75.9:1. Up to an S/N of 6.5:1, speed of response and number of response correct increased with both S/N ratio and TV lines-over-target. Performance varied directly with system TV line number as number of TV lines varied from 729 to 1029 lines. The higher line number was particularly effective at longer ranges and with smaller targets. There was an interaction between S/N ratio and TV lines-over-target: the S/N ratio had more effect on smaller targets.

Johnston (1968) used a closed-circuit TV system to display a terrain board with olive drab painted wood models of army vehicles: a 2.5-ton cargo truck, a 5-ton flat bed truck and a tank with a 90 mm gun. The TV camera looked down 30^{o} from the horizontal and presented a static view on a 4.6 inch wide by 3.5 inch high monitor. Viewing distance was fixed at 24 inches. By varying scan spot size, systems of 200, 400, and 550 Tv lines were achieved. The study examined both horizontal resolution and shades of gray at randomly presented ranges of 6, 9, and 12 thousand feet for effect on recognition time and recognition probability, with and without prior direct view by eye or the terrain.

Without previous direct view, the time taken to find targets was reliably different for the 10 observers, times were about 4.9 seconds at 200 lines of horizontal resolution, 4.2 seconds at 400 lines and 3.4 seconds at 550 lines. At all slant ranges, recognition probabilities were significantly different, but there were no reliable differences in recognition probability between levels of resolution. However, by analysis of variance, resolution was statistically significant (p .01), as was slant range (p .001), although shades of gray were not significant.

Swinney (1968) used 3", 6", and 9" displays viewed from a distance of 24". Variations in angular size of the display did not affect detection of people, but the smallest size of display was slightly poorer for vehicle detection.

variable, resolvable lines-over-target, which included both TV lines-over-target and S/N ratio, correlated highly with correct responses, accounting for 66% of the variance.

Semple and Gainer (1969) reviewed the literature up to that time on operator-reconnaissance display system performance, finding that the effects of many variables had been investigated, but that display size as a variable had been ignored. However, using the data from many studies and the sizes of the display used in each of them permitted a prediction of maximum probability of target detection that they termed "curiously accurate" for studies involving radar imagery or including factors such as noise or clutter in addition to target symbology. With display diameters of .2 to 15 inches, variations in display size did not influence target detection probability when displays were free of noise. However, addition of noise or of symbology markedly influenced detection probability for displays larger than .75 inch in diameter.

Meister and Sullivan (1969) reviewed the literature on Plan Position Indicator (PPI) displays and noted that a frequent recommendation in Human Factors Handbooks for the size of a CRT display is 7 inches. This is based upon PPI data and viewing distances of approximately 14 inches, with PPI sizes of 2 to 8 millimeters. They noted that larger scopes are recommended for larger target sizes and viewing distances. Thus, from the above it follows that a 14" display would be appropriate for a 28" viewing distance. Their main point is that the trade off is between PPI size and display size for PPI displays. As an example, they note that radar target detection

Levine et al. (1969) determined observer capability for identification of targets on a simulated cockpit TV display with various shades of gray and TV lines-over-target. Six trained observers viewed, on a TV CRT, 4 fighter aircraft on a uniform background with 4, 8, 12, 16, and 20 TV lines-over-target and with 3, 5, and 7 shades of gray. Performance was measured by speed of response and number of correct identifications. As shades of gray increased from 3 to 5 or 7, performance improved, with 5 and 7 not different. As TV lines-over-target increased, speed of response and number correct increased over the 4 to 12 TV lines-over-target range, but from 12 to 20 lines performance did not further increase. The authors conclude, with respect to TV lines-over-target, that a sensor-display system having 12 or more TV lines-over-target will be required to achieve high identification accuracy.

Levine et al. (1970), in a second study, examined the effects of signal-to-noise ratio (S/N) and TV lines-over-target. The imagery source was photographs taken from an aircraft with a KS-87 reconnaissance camera. Twenty target frames, 2 for practice and 18 for test, containing U-Haul trailers, boats and construction equipment were selected as being representative of tactical reconnaissance targets. A closed circuit TV camera was used to supply pictures for a TV display to 12 observers. The display thus simulated real time TV aerial reconnaissance. Target images had an average of 6, 9, and 11 TV lines-over-target and successively appeared at S/Ratios of 4, 8, 16, 32, 64, and 100 to 1. As S/N ratio and TV lines-over-target increased, the number of correct responses increased. A compound improves as PPIs or targets get larger up to a visual angle of about 60 minutes of arc, but that performance decreases continually as the scope becomes larger.

Erickson and Hemingway (1969, 1970) examined observer identification of military vehicles on various noncomplex backgrounds as seen on a TV display. They systematically varied the number of TV scan lines across vehicle images and the angular subtense of the images. Subjects were not rushed by time limits. The type of background influenced vehicle identification. The main experimental result was that, to insure a high probability of vehicle identification, at least 10 TV scan lines per vehicle were needed, as well as an angular subtense of the displayed vehicle image of over 14 minutes of arc. Noting that larger target images required fewer resolution elements, they proposed a constant product rule. This rule says that equivalent observer performance will be obtained when the product of the angular target image subtense at the eye and the number of resolved elements across the major axis of the image are constant.

Hemingway and Erickson (1969) examined the recognition of geometric forms or symbols on a CRT, independently varying the angular subtense, y, of the symbol at the observer's eye from 6 to 20 minutes of arc, and the number of resolution elements, x, per symbol height from 4 to 14. As the symbol's resolution increased, the number of minutes of arc required to attain a given level of probability of recognition decreased. Increasing either subtense or resolution increased recognition probability. The relationship was of the form P $(a/x^2) + (b/y^2)$, where a and b are constants. Lacey (1975), using pictorial targets, found a similar interaction of target subtense and resolution. Only for larger angular subtenses was increasing resolution effective. The observer had to be able to discern the increased details in the image. That the effects are even more complex was shown by Erickson and Hemingway (1969, 1970). Using sandy, plain, and foliage backgrounds, they found that the type of background influenced the interaction.

Bruns (1970) used 3 display sizes and 5 angular display heights varying for 6^o to 18^o. The identification ofTV on targets at known locations was essentially the same at all sizes. Bruns (1972), in a second study, measured both detection and identification. Again, performance was not influenced by the visual angle subtended by the display.

Scott, Hollanda, and Harabedian (1970) examined target identification using vehicle targets on a static display. They used overhead and side views (oblique). For most, but not all, vehicles the oblique view was better for purposes of the present report; the main result was that a satisfactory level of performance required about 20 TV scan lines per vehicle.

Semple (1971) combined data from Meister and Sullivan (1969) and from Weasner (1958). Weasner's data covered display diameters from 1/5 inch to 6 inches, while Meister and Sullivan covered 3 through 14 inches. Semple found that detection probability matched within a few percentage points for a 6-inch diameter, and the trend of the plotted curves from the two sources also matched well.

Wright and Gescheider (1971) investigated the effects of display size, luminance, and target-to-background contrast on detecting simple targets. They used simulated reconnaissance imagery. Detection was primarily affected by contrast. However, display size had a large effect on detection. As display size increased, errors increased (poorer accuracy) for all but the highest contrast conditions.

Parkes (1972) reviewed several studies, all of which showed a slight drop in performance at smaller angular display subtenses. However, the effects were not significant. He did a study in which the display size was constant while viewing distance changed. The display consisted of black and white photographs. Decreasing viewing angle from 21° X 15 $3/4^{\circ}$ to 9° X 7° yielded a slight, but nonsignificant, drop in performance.

Biberman (1973) notes that, at low altitudes where vibration and buffeting can be severe, the observer's head and the display are not synchronized in their motion. This results in angular motion which is greater at shorter distances. This means that larger displays at greater distances are preferable when vibration and buffeting are problems.

A study that looked at angular display size and used real-world targets found an advantage to larger displays. This was a study by Farrell and Anderson (1973) who examined search performance for various field sizes using high resolution small scale nonstereo photographic imagery with a high quality microstereoscope. Duplicate copies of the pictures were used for the two eyes. Sixteen photo interpreters were used as experimental subjects. The percentage of targets found for the 18° field was 27.6%. A large and statistically significant increase to 42.8% occurred for the 36° field. Further increase in field size to 54° and to 72° increased performance, in both cases, to 44.2%, not statistically significantly superior to the performance at 36°. While field size or apparent angular size of the field of view is not the same as display size for a CRT or other "screen" type of display, it does suggest that anhuur image field diameter probably needs to be no more than 36° to 54°. This is in line with the data from Enoch's study.

Both the size of a display and the distance from which it is viewed should be considered at the same time. Their combination determines the angular size of the display. Most available results from experiments show that the angular size of a display is a relatively unimportant variable when the eye can see or resolve all of the displayed information.

Kerbs and Graf (1973) examined target detection and recognition by varying several real-time display parameters: display size, display luminance, target-background, image quality, target type, and number of targets. Four military targets, jeep, tank, truck, and men, were imbedded into 48 different background. Each picture was presented with three levels of added noise. The four target images were originally taken with a forward-looking infrared (FLIR) sensor. Pictures were presented, by rear projection, onto display screens with 3, 6, and 9 inch diagonals. A Kodak Carousel projector was used. Display luminances for the pictures were approximately equated with neutral density filters. The pictures were presented for up to 15 seconds, or until recognition occurred. Observers were 12 college students. Detection time increased and percentage of targets detected decreased as display size increased. Thus, both measures gave poorer results with larger displays. A third measure, recognition time, decreased slightly with larger displays i.e., improved with larger displays. The percentage of all responses that were correct, or accurate, did not vary with display size. When target size was increased by magnification alone, performance did not improve. Findings not related to size will not be discussed. Our main interest in this study stems from its finding that the most efficient display size can be invariant with display size, can improve with larger displays, or can be worse with larger displays, depending upon the performance measure used.

The fact that, in comparing test conditions, the results can vary greatly, depending upon the performance measure used, as in the Krebs and Kraft study, has been known for some time. Self (1972), in a paper on performance measure, observer selection and reconnaissance/strike systems effectiveness, presented data showing the strong effects of performance measures.

Craig (1974) extended the 1969 and 1970 results of Erickson and Hemingway by embedding the vehicle targets in a complex cluttered background, systematically varying angular subtense, target background and number of TV scan lines across target images, and setting a time limit on available search time per scene. The basic images to be examined on the monitor of a closed-circuit TV system were 4 X 5 polaroid photographs of models of a tank, truck, van, and cab truck on a terrain board. Pictures were taken looking down on the models with an inclination of about 50 below the horizontal. For both high and low contrast vehicle images, the data indicated that the display should subtend at least 8, and preferably 10, degrees at the observer's eye. Target detection rates were high with at least 6 TV scan lines per target, but target identification, in contrast to detection, required approximately 20 lines per target. Detection did not improve significantly when scan lines per target increased above 6-8. They also found that overall display size had no effect upon target detection time, and that the total number of scan lines across the scene had no significant effect.

Barnes (1978) conducted two experiments to examine factors influencing the selection of display sizes for use in aircraft cockpits. The observers searched for unbriefed military targets as seen on a TV display. In both studies the image on display simulated images from a TV camera with a very narrow field of view of 2^{o} looking downward and obliquely forward at the terrain. The center of the field of view was at a simulated distance of 2.6 nautical miles. In the first, or screening study, moving imagery was used while visual angle, display size, signal-to-noise ratio (S/N), TV resolution, number of targets in the test strip, and simulated airspeed was varied. Nine inch and two inch displays were used with a terrain scale of 800:1. In the second study a series of still pictures were used, while contrast, visual angle, number of targets, S/N ratio, and configuration were varied. The important result of the first study was that the size of the display, independently of the size of the visual angle subtended by the target image, was relatively unimportant when MTF and visual angle were held constant. Actual values of performance were not given. Any improved performance that might result from viewing a larger display at a greater distance, while keeping visual angle constant, was negligible. In the second study, regression equations show that visual angle of target images on display is much less important than any of the other factors that were examined, but that the proportion of correct decisions increased with target visual angle. The size of the display necessary to detect targets depends upon how many targets are being looked for, target contrast, and configuration. The overall conclusion from the first experiment was that the physical size of the display (when MTF and visual angle were controlled) was relatively unimportant. The second experiment showed that detection could be predicted (though not well) from display size. This report is noteworthy in that most previous studies varied terrain coverage while varying display size, so that target image size didn't change, confounding terrain coverage and display size. One couldn't tell if results were due to display size or to terrain coverage, or to a combination of the two.

It is important that the raster or scan lines of a television or other scanning sensor not be readily apparent to an observer. Raster line structure tends to mask some of the displayed information. It is desirable, for maximum efficiency in using a display mode of scan lines, to keep scan lines just below visibility by insuring that, at the viewing distance used, they are angularly small. In the laboratory where there is no buffeting or vibration, it is often assumed that scan lines begin to interfere with visual perception when one line subtends one minute of arc at the eye. This value is based on an assumed visual activity of one minute of arc. One minute of arc is near the threshold of vision in the laboratory with a high contrast vision chart in good illumination. In airborne systems, particularly at low altitude, visual activity is usually closer to 2-3 arc minutes, depending upon contrast and luminance, according to Wulfeck et al. (1958) in "Vision in Military Aviation". In the laboratory, Thompson (1957) found that observers prefer a viewing distance at which raster lines subtend about 1 minute of arc. This is in line with the later findings of Bennett et al. (1966). Carel (1965) discusses various considerations about displays and recommends that airborne displays use 1,000 line TV rasters and that, at the viewing distance used, raster lines should subtend less than 3 arc minutes or be just below raster line visibility. These considerations set limits on display size. It appears, from the above discussion that, to avoid loss in visual capability in fixed installations, raster lines should subtend not more than 1, or at the most, 2 arc minutes, and in aircraft they should not exceed 3 minutes, with not over 2 preferable.

The research reports reviewed in the present paper, except Levine et al. (1969), do not discuss a rather important point: the number of scan lines across a target image is not the same number as the number of TV resolution elements over the target as referenced to the target. A large target image may be covered by many TV lines, but actual resolution of target details may be very low, even so low that the image is only an unresolved "blob", if even that. Many possible causes for target resolution being less than scan lines-over-target image are readily brought to mind: low contrast target, atmospheric haze, TV camera vibration, poor quality optics, improperly focused or unclean camera lens, improperly adjusted camera or display controls, electronic noise, etc. These factors degrade image resolution without changing the number of scan lines across the displayed image. The number of resolved elements across the target image is always smaller, frequently much smaller, than the number of scan lines across the target image.

The contrast, resolution, and angular size of displayed target images influence the probability that they will be notified and recognized, higher probabilities being associated with larger values of these variables. The available literature does attain some consensus on the minimum value of the target image angular subtense and the presented resolved elements across the image that are needed to obtain adequate observer performance. The system mission or goal demands sensor fields of view or terrain coverage that permit targets to appear with acceptable probability on the display and remain there long enough to be recognized and designated. The required sensor coverage and the required target image size and resolution permit calculation of a minimum display size for the viewing distance that will be used. Sensor and display resolution may require modification of display size to minimize scan line visibility or to fit a small space. The final display size that is selected will usually be a compromise between various conflicting requirements. Unfortunately, there is very little quantitative data upon the effects of observer performance of less-than-optimum display size.

This literature survey was done to obtain design guidance for selecting the size of imaging displays for use in finding targets. Data from simple laboratory research and from more complex laboratory simulation studies and field tests of equipment were examined. Much of the research used abstract targets, often on homogeneous backgrounds, and often in static situations. Usually, only target search and designation were involved, without the task loading imposed by piloting, navigation, hostile avoidance, etc. The researchers' interest was often in doing pure research rather than collecting data that would be useful for equipment design applications. Usually, important variables were not identified or measured, and when they were often been held constant rather than been varied systematically. When held constant, frequently they were held at values far from those of interest to many data users. Many studies lack realism, and it is not known to what extent lack of realism invalidates results for application to operational equipment in real situations. Some laboratory studies used terrain boards and closed-circuit TV (CCTV) to achieve some realism. The results must be applied with caution to the design of operational systems. Conversion of results from studies having less realism than terrain boards to obtain design values is even more dubious. When fudge factors or lab-to-field conversion factors are applied to correct laboratory results for application to operational situations, it must be realized that values so obtained are only educated guesses that are highly unlikely to be reliable valid specifications. Despite the obvious deficiencies in the technical and scientific literature, realistic, and effective display sizes can be selected based on available design guidance.

C. LESSONS LEARNED FROM THE LITERATURE REVIEW

1. As long as the angular size (or subtense at the observer's eye) is adequate, actual linear size of the display and of displayed target images is ordinarily of little consequence.

2. However, when vibration or buffeting is appreciable, larger displays at larger viewing distances are advantageous.

3. When the presence or the location of targets is unknown, detection and identification depend upon discerning details of the displayed target images, so that image size and resolution become critical.

4. Many studies have found that there are minimum requirements for the resolution and the angular size of target images if adequate observer performance is to be obtained against unbriefed targets.

5. Within limits, some trade-off of image size against image definition (resolution) is possible.

6. The optimum display size will vary greatly with the performance measure used.

7. Sometimes a large display is required to include enough field of view or terrain so that targets have an acceptable probability of appearing on the display.

8. If target images are of adequate size, with moving terrain imagery, too small a display will result in targets being on display too short a time to be detected or recognized.

9. Overmagnification must be avoided. A display that is too large for the resolution and field of view of the sensor will present a blurred image and also require too much search activity. A display can be too large.

10. Scan or raster lines, if visible, are annoying and can conceal information, so that displays should be small enough angularly for scan lines not to be conspicuous.

11. When very large fields of view of the external world provided by electronic sensors must be displayed, for example, hemispheric coverage, available display technology is inadequate: even at unity magnification, scan lines will be conspicuous and images will be somewhat blurred.

12. To display the entire field of view of a high resolution sensor may require a large display so that, at the viewing distance used, the observer can discern all of the fine target details provided by the sensor.

13. A display size that is the most efficient for target search, as defined by eye movements, may be far from optimum when other factors are considered.

14. The size of a display necessary to detect targets depends upon numerous factors or variables, so that display selection is not a simple procedure. Factors that are important include required terrain coverage, the size, configuration and contrast of displayed target images, sensor resolution, display viewing distance, and the number of targets to be found.

15. When target locations are known in advance, cues from surrounding objects and the terrain may permit adequate detection and acquisition with small displays and small poorly-resolved target images.

16. Systems with supposably optimum image and display sizes have not always yielded significant increases in operator performance over systems that, by theory, appear to be appreciably inferior.

17. Because of limited available space, actual systems seldom err in the direction of overly large displays: when display size is not optimum, it is almost always too small.

18. In practice, a display size and resolution is often selected to match an available sensor in the hope that this will permit mission accomplishment. Ideally, both display and sensor should be designed to meet mission requirements, taking into account observer characteristics.

SECTION III

SELECTING A DISPLAY SIZE

Depending upon the task or mission, a display can be too large or too small for efficient use. It is clear that if observation of a display is to result in finding and recognizing unbriefed targets, the images of the targets must be large enough and contain enough image details for them to be easily resolved and recognized. Numerous laboratory and field studies have found that finding targets most of the time requires that the angle subtended at the observers eye by the minimum linear dimension of the target be 10-20 arc minutes. Values nearer 20 than 10 are preferable, especially in the presence of vibration or buffeting. The image must also contain at least 8-12 target resolution elements for it to be recognized most of the time. Within limits, the probability of detection and recognition increase, while detection time decreases, as angular subtense and resolved target details increase.

Bigger target images, if adequate image details are visible to the observer, yield shorter target detection times. It might appear desirable, then, to configure a system with a display image scale that would present target images that would occupy a large portion of the total area of the display. In operational systems such a configuration would guarantee mission failure. When targets are unbriefed their location on the terrain is unknown as is their existence. No targets may be present. If the target image can cover much of the display, then very little terrain is on display at one time and the system has a very narrow field of view. For unbriefed targets, not knowing where to aim the sensor guarantees that the probability of a target's image ever appearing on the display will be very low. In many airborne applications, the system displays a moving image whose speed across the display is proportional to that of the vehicle carrying the sensor. In such a system, any target image that did happen to appear on the display would be on the display for so short a time and be moving so fast that the target would not be detected or recognized. At the other extreme, a very wide field of view or terrain coverage also guarantees mission failure. A very wide field of view greatly increases the probability that a target will be displayed, and in real-time systems the image moves much slower across the display. However, such a field of view will present minute target images, so that the observer's visual acuity may be inadequate to discern details of the image even if sensor and display resolution are adequate. Also a great amount of terrain must be searched.

Using a very large display close to the observer to combine a wide field of view and large angular subtenses of target images is not a viable solution. Even the best available very large displays, especially if they are adequately luminous for use in a cockpit in daylight, have quite limited resolution across the display. Also, space must be provided for cockpit instruments and controls and for pilot ejection. When a large display is examined from a short distance, the images of target images may be adequate in angular size. However, the large angular size of the display requires a great many eye fixations to search the whole display. In addition, lack of display resolution on quite large displays causes images to be blurred:

images are noticeably unsharp and lacking in fine details, electronic noise is excessive, edges of images are unsharp and contrast is degraded. Also, raster or other scan lines are visible, annoying, and will mask some information. In this situation, the observer's eye is capable of seeing more details than the display, and possibly the sensor, can provide. In addition, large displays are bulky, heavy, expensive and power-hungry. High electric currents may be required, while required very high voltages are hazardous and also may result in unreliable operation.

Cost, weight, volume, and electric power requirements may demand a small display, while target size, terrain coverage, sensor resolution, viewing distance of the display and observer vision may demand a large display. In such a situation, compromise is necessary and the compromise selected should be one that will permit an acceptable probability of task accomplishment or mission success. Clearly, for a given mission or task, a display may be too large or too small for optimum observer performance. A list of some of the factors influencing the choice of display size is presented in Table 1. Not considered in the table are factors, other than size, peculiar to the target's background and to the interaction of target and background characteristics.

By taking into account display size, the modulation and spot size and visual resolution of the observer for a given viewing distance, a lower limit to display size set by visual acuity may be determined. On a graph, visual response curves are plotted for displays of various sizes and display MTF curves for various display sizes. On the plots, the vertical axis is

TABLE 1

FACTORS+ INFLUENCING CHOICE OF DISPLAY SIZE

FACTOR	COMMENTS
1. Sensor Resolution	(a) Provide at least 8-12 + resolution elements across the maximum dimension of the target. (b) Observers should easily and clearly see all fine target details resolved by the sensor. High resolution wide angle sensors may require large high resolution displays. To avoid "empty" magnification blurr, low resolution sensors may require small displays.
2. Display Resolution	Should fully utilize sensor resolution, i.e., have about double the sensor resolution, and should exceed observer resolution.
3. Terrain Coverage	(a) Is often restricted by sensor resolution. (b) Large coverage: (1) Retains moving image targets longer on display, (2) Yields more contextual cues, and (3) Increases probability that the target will appear on the display.
4. Image Scale and Observer's Visual Acuity	Select a scale that yields an angular target subtense at the observer's eye of 12-20 minutes of arc.
5. Target Image Size	See "Image Scale": 12-20 arc minutes.
6. Display Magnification	See "Image Scale". Magnification must be enough to yield target images of 12-20 minutes of arc, but must not be excessive for sensor resolution to avoid excessive grain, noise, unsharp edges, reduced contrast and blur. Overmagnification unduly reduces "see ahead" distance.
7. Eye Fixations	More fixations are required on larget displays due to small instantaneous field of high acuity of the eye (Foveal Vision).
8. Power Consumption	Large displays use more power for display illumination or luminance. They are also bulky, heavy and expensive.

+ Not tabled are target characteristics, other than size, background characteristics and interaction of target and background characteristics. Viewing distance is allowed for in factors 4, 5 and 6.

resolution of the display in TV lines divided by display width. Curve intersections indicate the response limit of the display-observer system.

Rogers and Poplawski (1973) use this MTF type of analysis for a 28 inch viewing distance and an .008 inch CRT spot size to show the visual acuity limited resolution, (TV lines)/(display width) for 6, 9 and 12 inch displays. They find that the visual acuity-limited resolution for a 6 inch display is about 650 TV lines at 50% modulation. For a 12 inch display, the value is about 1250 TV lines at 43% modulation. Note that this value is for threshold observation, which is clearly undesirable. To detect and recognize more targets, they should be well above threshold, requiring a larger display. At the Hughes-Aircraft Company, say Rogers and Poplawski (1973), experimental studies have not found performance benefits with the larger displays called for by theoretical prediction that matches display and observer resolution. They conclude that it is thus difficult to justify the selection of display size on a resolution matching basis.

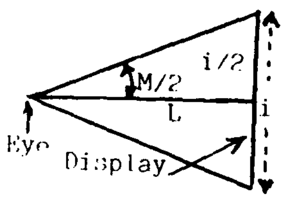
Carel et al. (1976) notes that one way to arrive at optimum display size is to use the inverse of the contrast sensitivity function as a "figure of merit". Keep in mind that there is not just one contrast sensitivity function for the average (or the 5th percentile or whatever) observer, for the function is different for different display luminances and display surround luminance ratios. For a given display luminance there is a different figure of merit curve for each viewing distance. The curves are plotted on a graph where the vertical axis is figure of merit and the horizontal axis is display height. In the example given by Carel, he says that the optimum display size varies with the viewing distance to keep the displayed information or target in the most sensitive region of the figure of merit curve. Changes in display luminance, target spatial frequency, element spatial frequency, etc. change the position along the horizontal (or display height) axis of the plot. In the example given by Carel et al., it is assumed that display luminance is 3500 cd/m^2, the TV has 448 active TV lines, and target definition is 16 cycles. Under these conditions, the figure of merit curves given in Carel's example peak at about 170 mm (6.7 inches) display height for a viewing distance of 420 mm (16.5 inches), and at about 350 mm (14 inches) for a 750 mm (29.5 inch) viewing distance.

SECTION IV

DISPLAY SIZE GEOMETRY

Human engineering guides and handbooks present formulas for calculating minimum display size based on assumptions about human visual capabilities and given viewing distances. The assumptions are not always given and derivations of the equations are not presented. When different values are assumed for visual capabilities or viewing conditions, it is not always clear how the formulas should be modified. In addition, some widely-used sources are in error, due to uncorrected typographic errors or to errors from copying incorrect formulas from other sources. For these reasons, it is of some value to derive some display size formulas and, with numerical examples, illustrate their application.

The detection and recognition of targets from examination of the target images on a display requires that the images be large enough to allow the observer to discern enough image details, provided that they are available from the sensor. The actual image size or maximum target image dimension, i, required varies with viewing distance, L, as shown in Fig. 1.



Let: L = viewing distance = eye-to-display distance.

i = maximum target image dimension.

M = angular subtense of target image.

From the Figure: Tan (M/2) = (i/2)/L, For small M,
Tan (M/2) = (M/2) radians = (M/2 minutes)/3438
Thus, Tan (M/2) = (M/2)/3438 = (i/2)/L,
From which, i = ML/3438

Fig 1. The Geometry of Image Size and Angular Subtense.

In Fig. 1 it is shown that:

$$i = ML/3438 \qquad \text{Eqn. (1)}$$

Where:

i = maximum dimension of target image
L = viewing distance
M = angular subtense of target image in minutes of arc

Laboratory data from various researchers on target detection and recognition indicate that, for adequate observer performance, the angular subtense of the target image at the observer's eye should be 10 to 20 minutes of arc. For a value of M = 12 arc minutes and a viewing distance of L = 12 inches, equation (1) yields i = (12)(12)/3438 = .042 inches. This is why handbooks sometimes give the formula display size in inches = D = .042 (target range/target size), i.e., D = .042 (R/T), range and size in same units, e.g., feet, and say that, for a 12-inch viewing distance, a target image on the display should have a minimum linear dimension of .042 inches. In an aircraft, an appropriate viewing distance would be 28 inches, and for L = 28", equation (1) yields i = (12)(28)/3438 = .098", or approximately .1 inch.

When looking for targets of a given size, with a given viewing distance and value of angular subtense of the target image, the amount of terrain required to be displayed will determine the minimum display size. Calculation can be quite complex for non-mapping displays, such as those for forward-looking IR (FLIR) or forward-looking low-light-level TV (L^3TV). For a mapping type of display, such as that of rectified-image side-looking radar (SLR), image scale is uniform over the display and calculation is simple. For such a display, (image size)/(display size) = (target size)/(terrain size), where size means largest dimension. Using letters i/D = T/R, from which i = TD/R, value of i is also available from equation (1), namely, i = ML/3438. Equating the two values of i, image size, yields TD/R = ML/3438, from which D = (LMR)/(3438T). For R in statute miles of 5,280 feet each, and D in inches, this equation becomes D = (12)(L_{inches}/12)(M)(R_{miles} x 5,280)/3438T = 1.536 LRM/T, i.e.:

$$D = 1.54\ LRM/T \qquad \text{Eqn. (2)}$$

Where:

D = display size in inches
L = viewing distance in inches
R = range to target in statute miles
M = target image angular subtense in arc minutes
T = maximum target dimension in feet

For an angular subtense of M = 12 arc minutes for a target image, and a viewing distance of L = 28 inches, Eqn. (2) becomes D =(1.536)(28) (12) (R/T), i.e.:

$$D = 516\ R/T \qquad \text{Eqn. (3)}$$

Where:

For, a 12-arc minute target image on a display 28 inches away from the observer:
D = display size in inches
R = range to target in statute miles
T = target (not image) size in feet

As an example of the use of Eqn. (3), let T = 100 feet, i.e., 100-foot targets, and let the display cover or include 3 statute miles of terrain. Then, for the 12-minute target images and the 28-inch viewing distance assumed in Eqn. (3), D = (516)(3/100) = 15.5 inches. Thus, for the conditions of this example, display size should not be less than 16 inches. If one assumes, as some researchers believe should be the case, that a value of M = 20 arc minutes is preferable, then D = (1.54)(28)(20) (R/T) = 862 (R/T), and the example at the start of this paragraph would yield D = 26 inches. That is a large display, and to attain its equivalent might require a virtual image display device, such as a helmet-mounted display (HMD).

Some display devices, such as head-up displays (HUDs), provide a virtual image, at a large optical distance from the eye, usually at optical infinity. The optical distance of a virtual image may, for ease of understanding, be thought of as that distance upon which, or to which, an optical telescope, aimed at the image, must be focused to clearly display the image. The linear size of a virtual image located at a large optical distance is not useful for selecting a display size or for making size comparisons. Instead, the size of virtual images is more usefully stated in terms of their angular subtense at the observer's eye. Thus, the "size" of a HUD display may be 15° of arc, and an HMD may have a size of 40°, i.e., a 40° apparent field of view.

For virtual image displays, the question of interest is: "what is the equivalent size of a real image display, i.e., what size of real image display subtends the same angle at the observer's eye"? The subtended angle of a real image display depends upon its maximum dimension, D, and the distance, L, from which the real image is viewed. The size, W, in terms of angular degrees subtense at the observer's eye, of a real display is found from the equation $\tan(W/2) = (D/2)/L$. Solving this equation for D yields:

$$D = 2\,L \tan(W/2) \qquad \text{Eqn. (4)}$$

Where:

D = linear size of an equivalent real-image display viewed from a distance L
L = viewing distance in same units (inches, etc.) as D
W = angular subtense, in degrees, of the total display image

Note that the equivalent size of a real image display corresponding to a given virtual image display size must be stated for a specified viewing distance from the real image. For a viewing distance of 28 inches, appropriate for the cockpit of an aircraft, Eqn. (4) becomes:

$$D = 56 \tan(W/2) \qquad \text{Eqn. (5)}$$

Where:

D = linear size of an equivalent real-image display viewed from 28 inches, W = angular subtense of the display.

As an example of finding a real-image size equivalent of a virtual image display, by use of Eqn. (5), suppose that the field of view, W, of an HMD is 40°, Eqn. (5) then gives $D = 56 \tan(40^{\circ}/2) = 20.38$ inches. Thus, an HMD with a 40° field of view is equivalent in size to, i.e., subtends the same angle as, a 20.4 inch CRT viewed at 28 inches. Similarly, for a viewing distance of 10 inches, a real-image directly-viewed display, e.g., a CRT, must have a diameter of $D = 20 \tan(40^{\circ}/2) = 7.3$ inches to be equivalent, sizewise, to an HMD display that has a 40° angular field of view.

The maximum sensor field of view (FOV) of a sensor having L total active scan lines that can place N scan lines across a target of angular subtense A is of some interest. Let the targets of interest be T feet tall, as seen from the sensor, and be at a range of R feet. Under these conditions, (scan lines-over-target)/(total number of scan lines) = (target angular subtense)/(total sensor field of view), i.e., $N/L = A/(FOV)$. Now, at range R, a target of height R subtends an angle of A, or half the target subtends an angle of A/2, so that $\tan(A/2) = (T/2)/R$.

Since A is, normally, quite a small angle, $\tan(A/2) = A/2$ in radians = (A/2 in degrees)/57.29. Thus, $(T/2)/R = (A/2)/57.29$, from which:

$$A = 57.29\ T/R \qquad \text{Eqn. (6)}$$

Where:

A = Target (not target image) angular subtense in degrees.
T = target height in feet.
R = Range in feet to the target.

Substituting this value of A in the equation $N/L = A/(FOV)$, derived above, yields:

$$FOV = 57.29\ LT/NR \qquad \text{Eqn. (7)}$$

Where:

FOV = sensor field of view in degrees
N = scan lines across the target
L = total active scan lines
A, T, R as defined in Eqn. 6.

To illustrate the use of equations (6) and (7), suppose that the target range is R = 2 miles, the target height is T = 10 feet, total active scan lines is L = 750 lines, and that the required lines-over-target is N = 12 lines. For these conditions, equation (6) yields $A = (57.29)(10)/(2 \times 5,280) = .0543^\circ$ = 3.26 arc minutes = target angular subtense at the sensor. Since a human observer requires a target angular subtense of 12 to 20 arc minutes, a display magnification of 12/3.26 to 20/3.26, or 3.7 to 6.1 times would be required, yielding target images subtending, at the eye, 12 to 20 arc minutes.

Equation (6), for the total sensor field of view, yields $FOV = (57.29)(750)(10)/(12)(2 \times 5,280) = 3.39^\circ$. Since a display magnification of 3.7 to 6.1 times is required, FOV of the display with this amount of magnification would be $(3.7)(3.39^\circ)$, i.e., 13° to 21°.

For some applications of head-up displays and helmet-mounted displays (HUD's and HMD's), the displayed image must be the same size, angular-wise, as the eyeball-viewed scene i.e., unity magnification is required. Let eye resolution be B arc minutes, or B/60 degrees, i.e., one active scan line subtends B arc minutes, then, for a total number of active scan lines of L, the sensor field of view is given by:

$$FOV^* = BL/60 \qquad \text{Eqn. (8)}$$

Where:

FOV^* = sensor field-of-view = display field-of-view, in degrees (unity magnification).

B = eye resolution in arc minutes.

L = total number of active scan lines.

As an example of the use of this equation, suppose that eye resolution $B = 1$ arc minute of visual acuity and that the display has 500 active scan lines, then the formula yields $FOV^* = (1)(500)/60 = 8.3^{\circ}$ angular display size. For an airborne case, $B = 2$ arc minutes is more realistic, and the equation yields $FOV^* = (2)(500)/60 = 16.7^{\circ}$. Even with a 1000 active scan line display, airborne use requires only a $(2)(1000)/60 = 33.3^{\circ}$ field of view, and a larger field of view than this would probably make scan lines too conspicuous. Erickson et al (1974, Page 65), using a 1 arc minute per scan line criterion, says "It can be seen that a HUD size of 10° or greater is clearly adequate for displaying any feasible line scan imagery, even a 2-wide by 1-high aspect ratio format". However, he notes that vibration, sensor noise, low-contrast targets, and moving imagery may change requirements.

In some situations it is of value to be able to examine all parts of a display without moving the head. This is possible when the maximum dimension of the display, diameter for a round display and diagonal for a rectangular display, does not exceed 30°. The angle A depends on both display size and viewing distance, being given by the equation $A = 2\,\mathrm{Tan}^{-1}(S/2D)$, where S is maximum display dimension and D is viewing distance, both S and D being in the same units of measurement. Thus, $S = 2D\,\mathrm{Tan}\,(A/2)$. For a viewing distance of 28 inches, a common value for aircraft cockpits to permit a clear pilot ejection envelope and an angle of 30°, this equation yields $S = (2)(28)\,\mathrm{Tan}\,15^{\circ} = 15.0$ inches. Thus, to avoid head movement while searching a display from a viewing distance of 28 inches, the maximum display dimension cannot exceed 15 inches. Other factors may dictate a smaller display, and a small amount of permissible head movement would permit a larger display.

Display size, sensor field of view, image size, resolution and rate of motion are related variables, i.e., changes in some of them cause changes in others. Some aspects of these relationships are summarized in the following points:

1. When the field of view of the sensor is given or fixed and all of it just covers the display:

Larger displays yield larger target images that move faster on the display, but remain on the display for the same amount of time. In other words:

(A) Target image sizes and angular subtenses are directly proportional to display size.

(B) Target image motion rate, both absolute and angular, is directly proportional to display size.

(C) The time that a target image remains on the display does not change with changes in display size.

2. When the sensor is "zoomed" (sees a narrower field of view) and its field of view just matches or covers the display:

"Zooming" narrows the field of view, yielding target images that are larger and better resolved, i.e., more target details are visible, but target images move faster and remain on display for less time. With a narrower field of view, targets are less likely to be included, targets lost through "Pop-up" or evasive maneuvers are more difficult to reacquire, terrain is more difficult to match to maps, and navigation check points are more likely to be missed. With very narrow fields of view, one might fly over an army and not know it. Problems from a narrow field of view are not alleviated by larger displays. In other words:

(A) Target image size is directly proportional to the product of zoom magnification (or sensor field of view) and display size.

(B) Scan lines-over-target is directly proportional to zoom magnification (or sensor field of view)

(C) Target image motion rate, angular and absolute, is directly proportional to the product of zoom magnification (or sensor field of view) and display size.

(D) Time on the display of target images is inversely proportional to zoom magnification (or sensor field of view), but does not vary with display size.

SECTION V

AN EXPERIMENT WITH VARIOUS SIZES OF STATIC SIDE-LOOKING RADAR PICTURES

The present investigation measured observer target detection time or reaction time with a radar sensor against three types of target: airfields, railroad yards and tank farms. Three different picture sizes were used, corresponding to different sizes of displays. The smallest, 5 x 5 inches, represents a display screen size that is easily and inexpensively implemented in almost any airborne system. The largest one, 15 x 15 inches, is about as large as is practical in many airborne systems. The pictures are identical in ground coverage, only picture size varies.

A. LEVEL OF DIFFICULTY OF STIMULUS MATERIAL

How difficult it is to find a target in a scene or on a picture or display may be measured by the time taken to find it, i.e., by the response time or detection time. It may also be measured by the number of errors or incorrect choices. A target that is easily found may be thought of as having high visibility. Here, difficulty varies inversely as visibility. It appears likely that if most targets are so visible as to be found almost instantly by most observers on all of the displays used in a study, then the size of the displays will be inconsequential. Fractional second differences in response times are likely to be insignificant for practical purposes. However, if most target images are very difficult to find, some of them will not be found. When, after an extended search, some test subjects do not find some of the targets, difficult problems arise. Extended search times could not be allowed in the present study because test subjects had to be fitted into tight testing schedules. Permitting extended search times would prevent testing some observers on all of the pictures planned for the test. Also, missed targets create problems in statistical analysis of response time data. In addition to time and data analysis problems, very difficult targets yield highly variable target detection times. High variability across observers, with consequent large standard deviations, make statistical analyses less sensitive to real reaction time differences between picture sizes. For these reasons, the present study did not examine the influence of display size on difficult targets. Instead, the intent was to examine picture size influence on detection time against targets that range in difficulty from very easy to moderately difficult. Targets in this range are the ones that can be found quickly enough and often enough to be acted against by weapon systems. The pictures that were used were selected by inspection from a large number of available pictures. Pictures were not used when it appeared that the target would be very difficult to find.

B. THE PICTURE MATERIAL

The pictures that were used in testing observers were obtained by an airborne high resolution side-looking radar (SLR). For an introduction to SLR, see Self (1978) or Jensen et al. (1977). The ground resolution of this radar was approximately 50 feet. The image scale, for the medium size pictures, was about 1:90,000, and was about 1:180,000 for the small pictures. Thirty-six pictures or scenes were selected. The target on 12 of them was an airfield, 12 included a railroad yard and 12 contained a tank farm. Each target was different, i.e., there were 36 different targets. The 36 scenes were each prepared in 3 square picture sizes: 5 x 5, 10 x 10 and 15 x 15 inches on a side. Since each scene occurred in three picture sizes, the total number of pictures was 108. The pictures were black and white (monochrome) transparencies on photographic film. They were viewed on a light table by transmitted light. Transparencies, rather than paper prints, were used to retain as much as possible of the wide dynamic range of the radar sensor.

The maximum target image dimension for the 36 targets is given in Table 2. It lists image sizes for the 10 x 10 inch (medium) sized pictures. Note from the table that the airfield target images varied from 14 mm to 49 mm, railroad yards varied from 15 mm to 60 mm and tank farm images varied from 6 mm to 22 mm. Thus, tank farms were the smallest targets. For the small (5 x 5) pictures the listed values must be divided by 2, while for the large (15 x 15) pictures the tabled values must be multiplied by 1.5 to obtain target image sizes. The smallest target images are the two 6 mm tank farms. On the small size pictures their maximum dimension is 3 mm. Observers could examine the pictures at any viewing distance that they desired. At a viewing distance of, for example, 12 inches, the 3 mm images subtended at the observer's eye and angle of about 34 minutes of arc. This is large enough to be seen easily. Thus, none of the images of targets were difficult to see or to examine because of their size.

TABLE 2

MAXIMUM TARGET DIMENSION*

AIRFIELDS			RR YARDS			TANK FARMS		
No.	M.M	Rank	No.	M.M.	Rank	No.	M.M	Rank
1	22	10	13	17	9	25	19	2
2	36	4	14	19	7.5	26	10	8
3	14	12	15	15	11.5	27	6	11
4	20	11	16	52	2	28	18	3.5
5	28	7	17	19	7.5	29	22	1
6	23	8.5	18	60	1	30	8	9
7	42	2	19	15	11.5	31	6	11
8	23	8.5	20	41	4	32	14	5
9	49	1	21	21	6	33	13	6
10	40	3	22	29	5	34	18	3.5
11	32	6	23	50	3	35	12	7
12	34	5	24	16	10	36	6	11
$\bar{X}$	30.25			29.50			12.67	

*Values in the Table are listed for the medium size pictures. For the small pictures, divide the table values by 2, and for the large pictures, multiply table values by 1.5. Ranks for sizes do not vary with picture size. The ranks run from largest, rated 1, to the smallest, which has a rank of 12.

C. EXPERIMENTAL DESIGN

From a large set of pictures, twelve were selected that contained one airfield target. Twelve others were selected that contained only one railroad yard target, and 12 were chosen that contained only one tank farm. The ground area of the 36 scenes did not overlap. Each of the 36 scenes was duplicated in small, medium, and large picture sizes for a total of 108 pictures. Every observer was tested only once on each of the 36 scenes to prevent memory effects. Thus, each observer saw only one third of the 108 pictures. All observers were tested first on 12 airfield pictures, then on 12 railroad yard pictures and, finally, on 12 tank farm pictures. For each type of target there were 4 small, 4 medium, and 4 large pictures. The order of presentation of these three sizes of pictures of each type of target was varied from one observer to the next. For example, the first of the 72 observers was tested first on small picture airfields 12, 1, 6 and 2 in that order, while the second observer was tested on small airfields 4, 9, 8 and 7, after first being tested on 4 large picture airfields. The 4 pictures at each size and type were randomly selected from the 12 of that type, with the constraint that every one of the 108 pictures was tested 24 times, i.e., on 24 different observers. Even with highly trained observers, such as were used in the present study, the order of presentation of pictures sizes may have an effect on response time. To distribute order effects over picture size, the three picture sizes were varied in order of presentation from one observer to the next. Any one observer was tested with the same size order for all three types of targets. With 3 picture sizes there are 6 possible orders of presentation. Each order of presentation was used an equal number of times so that, with 72 observers, each order of presentation of sizes occurred 72/6 = 12 times.

Unknown to the observers, the 4 sides of the 108 pictures were labeled 1 through 4 on the back of the frame. The side facing away from the observer was varied from observer to observer, using the numbers on the back, to counter any picture orientation effect between types of targets. Any one observer had all of his pictures presented with the same numbered side, for example 3, facing away from him, i.e., at the "top".

With 72 observers, all tested against every one of the 36 targets, and with 3 picture sizes per scene or target, each of the 108 targets received 72/3 = 24 response times or target detection times. The total number of response times or test scores in the present study was (24 observers/picture) x (108 pictures) = 2,592 test scores. Alternatively, (36 test scores/observer) x (72 observers) = 2,592 test scores.

D. TEST ADMINISTRATION

The observer sat at a light table. Pictures in the form of monochrome transparencies were placed in from-fitting transparent film holders whose opaque covers could be quickly removed to expose the picture. Film holders were on top of the light table. Before testing commenced, each observer was practice tested on examples of each of the three sizes of picture so that he was thoroughly acquainted with the test procedure and the image scales of the pictures. For each scene with, for example, an airfield, he was told:

"Find the airfield, ready, now." The picture was uncovered simultaneously with the starting of the clock. The word "now" was uttered about 1 second after the word "ready". The clock was an electric one whose pushbutton control was held in the administrator's hand. The observer was instructed to say "there" when he found the target. The clock was stopped when he said "there". He then designated the target by placing his finger tip on it. By operating the time clock at this utterance of "there", rather than waiting for observers to point out the target, it was not uncommon to obtain response times of less than one second. If he pointed to a non-target, he was told "no" and the clock was restarted with the pushbutton. Both the time in seconds, to the nearest .1 second, to find the target and the number of errors, if any, were recorded.

As previously mentioned, each observer was tested on only 36 of the 108 pictures, with an equal number of small, medium and large pictures for each of the three types of targets. Thus each observer saw all targets, but only saw one-third of the 108 pictures used in the study. Over the entire study, every one of the 108 pictures was presented to 24 observers, though not the same 24 observers, for every picture. The 72 observers in this study were SAC and TAC Radar Navigators.

E. RESULTS

(I) Target Difficulty

As discussed earlier, the pictures used in this study were selected to avoid targets that were very difficult to find. The success of this

TABLE 3

RESPONSE TIME FOR AIRFIELD TARGETS

NO.	SMALL SIZE PICTURES (5x5) 1	2	3	4	5	6	7	8	9	10	11	12
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	.8	.7	1.1	1.5	1.7	.8	.6	.8	.8	.7	1.9	1.0
	1.2	.7	1.3	2.6	2.5	.9	.7	.8	.8	1.0	2.1	1.2
	1.3	.7	1.7	3.5	2.7	.9	.8	.8	.9	1.1	2.3	1.2
	1.3	.8	1.9	4.0	3.2	.9	.8	.8	.9	1.3	2.3	1.3
	1.6	.9	3.8	4.4	3.7	1.1	.8	.9	.9	1.3	2.8	1.5
	1.8	.9	4.8	4.7	3.9	1.2	.8	.9	.9	1.4	2.8	1.6
	1.9	.9	5.9	4.8	3.9	1.4	.8	1.0	1.0	1.6	2.9	1.7
	2.6	.9	6.1	5.4	6.2	1.4	1.1	1.1	1.0	1.8	3.1	1.7
	2.6	.9	6.2	5.7	6.3	1.5	1.1	1.1	1.1	2.3	3.4	1.8
	3.0	.9	6.2	6.0	6.5	1.5	1.1	1.1	1.2	2.3	3.5	1.9
	3.0	1.1	6.3	6.1	7.8	1.5	1.2	1.2	1.3	2.4	4.0	2.1
	3.4	1.1	6.4	7.0	8.8	1.6	1.2	1.3	1.3	2.4	4.7	2.1
	3.8	1.2	6.8	7.1	9.2	1.7	1.2	1.4	1.3	2.6	5.4	2.3
	4.3	1.3	6.8	7.1	9.6	1.9	1.2	1.5	1.4	2.8	5.5	2.4
	5.0	1.4	7.2	7.9	12.1	2.1	1.2	1.5	1.4	2.8	7.1	2.5
	5.6	1.5	7.2	8.0	12.4	2.1	1.2	1.5	1.5	3.1	8.7	2.6
	5.7	1.5	8.9	9.1	14.6	2.1	1.3	1.6	1.5	3.2	10.0	2.8
	5.8	1.5	9.9	10.0	17.1	2.5	1.4	1.8	1.6	3.4	10.4	2.9
	7.1	1.7	11.0	13.6	18.5	2.6	1.4	1.8	1.7	3.4	15.0	2.9
	8.0	1.7	11.4	13.7	24.9	2.7	1.5	1.8	1.7	3.6	28.9	3.0
	13.2	1.9	14.1	13.8	25.5	2.8	1.6	2.1	1.8	4.3	33.0	3.2
	14.3	2.4	18.5	13.9	26.2	3.9	1.7	2.7	1.9	5.0	48.4	3.9
	20.6	3.6	28.5	16.6	31.1	5.6	1.7	3.4	1.9	5.4	70.5	4.2
	27.2	3.8	49.7	29.8	42.8	11.6	2.6	3.8	2.4	7.1	125.2	5.3
MEDIAN	3.60	1.16	6.59	7.02	9.00	1.66	1.19	1.35	1.31	2.49	5.05	2.21
MEAN	6.05	1.42	9.65	8.60	12.55	2.35	1.21	1.53	1.34	2.76	16.83	2.38

NO.	MEDIUM SIZE PICTURES (10x10) 1	2	3	4	5	6	7	8	9	10	11	12
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	1.4	.8	1.3	1.5	1.3	.8	.7	.7	.8	.9	.8	.9
	1.7	1.0	1.9	1.8	1.3	.9	.7	.9	.8	.9	1.2	1.1
	1.8	1.0	1.9	2.6	2.9	1.1	.7	1.0	.9	1.1	2.4	1.4
	1.9	1.0	2.2	2.7	3.1	1.1	.8	1.0	.9	1.1	2.4	1.4
	2.0	1.0	2.7	2.7	3.2	1.1	.9	1.1	.9	1.1	2.5	1.5
	2.2	1.1	2.8	3.5	3.3	1.1	.9	1.1	.9	1.2	2.9	1.5
	2.3	1.2	3.3	3.6	4.0	1.3	1.0	1.2	.9	1.3	2.9	1.6
	2.7	1.2	4.2	4.1	4.2	1.3	1.0	1.2	1.1	1.4	3.0	2.0
	2.7	1.2	5.0	4.2	4.3	1.5	1.0	1.2	1.1	1.5	3.2	2.1
	2.8	1.2	6.4	4.3	4.6	1.6	1.1	1.3	1.1	1.8	3.2	2.1
	3.8	1.3	7.1	4.4	7.0	1.6	1.1	1.4	1.2	1.8	5.5	2.4
	4.0	1.4	7.5	5.7	7.8	1.7	1.2	1.4	1.4	2.0	5.8	2.7
	4.4	1.4	8.5	5.8	8.6	1.7	1.5	1.6	1.5	2.0	7.0	2.7
	4.7	1.5	10.3	6.3	9.4	1.8	1.5	1.7	1.5	2.1	8.1	2.7
	10.6	1.6	11.0	6.5	10.9	1.8	1.6	1.7	1.5	2.1	9.6	2.7
	14.1	1.6	11.4	6.9	11.1	1.9	1.6	1.8	1.6	2.2	14.1	2.8
	14.7	2.0	11.6	7.3	13.1	1.9	1.6	1.9	1.7	2.4	18.3	2.9
	18.4	2.1	16.6	7.6	14.2	2.1	1.6	2.0	1.7	2.4	19.0	3.0
	18.7	2.3	17.1	7.7	15.3	2.2	1.8	2.0	1.7	2.5	20.9	3.0
	19.5	2.4	18.1	7.7	18.4	2.2	1.8	2.3	1.7	3.0	24.0	3.0
	20.0	2.4	18.9	7.8	22.1	2.4	1.8	2.3	1.8	3.3	24.2	3.4
	20.3	2.8	19.3	8.2	24.8	3.0	2.0	2.5	2.1	3.4	44.8	4.2
	22.9	2.8	21.6	11.1	28.0	3.2	2.3	2.8	9.6	5.8	72.9	8.1
	34.7	3.5	24.4	11.8	49.4	4.0	2.4	4.9	22.2	7.3	116.2	9.7
MEDIAN	4.20	1.40	8.00	5.75	8.20	1.70	1.34	1.51	1.44	2.00	6.40	2.64
MEAN	9.68	1.66	9.80	5.65	11.35	1.80	1.36	1.71	2.52	2.28	17.25	2.87

NO.	LARGE SIZE PICTURES (15x15) 1	2	3	4	5	6	7	8	9	10	11	12
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	1.2	.9	1.1	2.6	2.4	.7	.7	.9	.8	.8	1.7	.9
	1.4	.9	1.5	3.4	2.5	1.1	.8	.9	.9	.8	2.0	.9
	1.6	.9	2.4	3.8	2.8	1.2	.8	1.0	.9	.9	2.3	.9
	2.0	.9	2.5	3.8	4.1	1.5	.8	1.0	.9	.9	2.5	1.0
	2.0	.9	2.6	4.4	4.2	1.5	.9	1.1	1.0	1.0	2.8	1.3
	2.3	1.1	3.4	4.5	5.1	1.5	1.0	1.1	1.0	1.2	2.8	1.6
	2.5	1.1	4.4	4.9	6.3	1.5	1.0	1.2	1.0	1.2	2.9	1.8
	3.0	1.1	4.7	5.3	6.3	1.6	1.0	1.3	1.1	1.6	3.0	2.0
	3.1	1.2	5.0	5.4	6.4	1.6	1.1	1.4	1.1	1.7	4.0	2.0
	3.7	1.2	7.4	5.6	6.6	1.7	1.1	1.5	1.2	1.8	4.4	2.0
	4.3	1.2	7.9	6.5	7.3	1.7	1.1	1.6	1.2	1.9	5.2	2.0
	4.4	1.2	8.1	8.0	7.4	1.7	1.2	1.7	1.2	2.2	7.8	2.1
	6.0	1.5	8.8	8.0	7.6	1.9	1.3	1.8	1.3	2.4	8.1	2.2
	7.8	1.5	9.5	8.5	7.7	2.2	1.3	1.9	1.4	2.4	8.9	2.4
	9.4	1.7	9.6	10.5	7.9	2.4	1.4	1.9	1.4	2.4	9.1	2.7
	9.9	1.8	10.6	13.7	8.2	2.5	1.5	2.1	1.6	2.5	11.0	2.8
	11.6	1.8	13.4	14.3	8.6	2.6	1.5	2.3	1.6	2.7	13.2	3.4
	12.4	1.8	16.5	17.1	11.7	2.6	1.6	2.7	1.6	2.7	14.6	3.5
	12.6	1.9	18.7	18.2	12.2	3.0	1.7	2.7	1.6	3.1	22.7	4.1
	17.6	2.0	19.1	19.1	14.4	3.1	1.7	2.7	1.7	3.5	24.9	4.2
	22.8	2.2	20.9	23.0	18.4	4.5	1.8	2.8	1.8	3.8	29.2	4.5
	34.9	2.3	23.2	36.0	21.3	5.5	1.8	2.9	1.9	4.3	41.2	7.8
	39.1	2.5	27.5	45.0	22.6	6.7	1.8	2.9	2.0	5.0	47.5	8.3
	52.9	3.1	30.4	48.0	34.8	6.6	2.8	3.9	3.5	6.2	69.8	9.8
MEDIAN	4.70	1.28	8.45	8.00	7.50	1.80	1.24	1.75	1.26	2.30	7.96	2.15
MEAN	11.14	1.53	10.80	13.32	9.87	2.50	1.32	1.89	1.40	2.33	15.06	3.09

TABLE 4

RESPONSE TIME FOR RAILROAD YARD TARGETS

NO.	SMALL SIZE PICTURES (5x5) 13	14	15	16	17	18	19	20	21	22	23	24
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	1.8	1.8	1.4	.8	.8	.8	1.3	.9	1.0	2.5	1.8	1.1
	3.5	1.8	1.6	1.0	.8	.8	1.5	1.0	1.1	2.6	1.8	1.3
	4.8	1.9	1.7	1.1	.9	.9	1.7	1.1	1.2	3.0	1.8	1.3
	4.9	1.9	2.0	1.4	.9	1.0	1.7	1.4	1.3	3.1	1.8	1.5
	6.2	1.9	2.4	1.4	1.2	1.0	2.0	1.4	1.3	3.7	2.9	2.0
	6.4	2.1	2.5	1.5	1.4	1.0	2.3	1.5	1.5	3.8	3.3	2.1
	6.4	2.1	2.6	1.5	1.5	1.0	2.3	1.6	1.5	4.9	3.4	2.2
	6.7	2.5	2.7	1.7	1.5	1.3	2.5	1.6	1.7	5.2	4.3	2.3
	6.9	2.9	2.8	1.8	1.8	1.3	2.7	1.7	1.7	5.3	4.6	2.5
	7.9	2.9	3.0	1.8	2.1	1.3	2.9	1.7	1.9	5.4	4.7	3.4
	8.0	2.9	3.0	1.8	2.6	1.4	3.1	1.8	2.0	5.8	4.7	3.4
	8.1	3.0	3.8	1.9	2.6	1.4	3.4	1.8	2.0	5.9	5.0	3.5
	8.1	3.2	3.9	2.0	4.8	1.5	3.4	2.0	2.2	5.9	5.4	3.8
	9.2	3.4	3.9	2.2	4.8	1.5	4.1	2.1	2.4	6.2	5.8	4.9
	13.4	3.4	4.0	2.3	7.4	1.6	4.2	2.2	2.4	6.2	6.0	5.0
	14.3	3.7	4.4	2.3	10.0	1.6	5.4	2.3	2.5	6.5	6.3	5.8'
	16.7	3.7	4.4	2.6	10.2	1.7	6.2	2.6	2.7	6.9	7.4	5.9
	18.2	3.8	4.9	2.7	14.5	1.9	6.2	2.8	2.8	7.5	8.0	6.5
	28.6	3.9	6.7	2.7	17.4	2.4	6.2	2.8	3.0	8.6	9.8	6.6
	41.0	4.1	9.6	2.8	22.8	2.9	6.5	3.0	3.1	8.7	11.0	7.6
	43.5	4.3	10.9	2.9	24.9	3.2	7.4	3.0	3.4	10.3	12.8	8.7
	110.3	6.0	20.9	3.1	26.6	4.0	9.7	6.5	4.1	10.6	23.4	11.1
	169.2	6.5	23.2	3.4	41.2	10.7	11.2	7.7	4.6	18.8	24.7	24.2
	352.6	7.8	33.1	3.9	41.2	202.8	15.6	8.0	4.7	19.9	88.2	40.4
MEDIAN	8.10	3.10	3.87	1.95	3.70	1.45	3.40	1.91	2.01	5.90	5.20	3.65
MEAN	37.41	3.40	6.64	2.11	10.16	10.38	4.73	2.80	2.34	6.97	10.37	6.56

NO.	MEDIUM SIZE PICTURES (10x10) 13	14	15	16	17	18	19	20	21	22	23	24
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	1.6	1.5	1.1	1.0	.7	.9	1.3	1.0	.9	1.9	1.5	1.2
	2.2	1.7	1.3	1.1	.9	.9	1.3	1.2	1.2	2.7	1.6	1.3
	2.4	1.7	1.3	1.3	.9	1.0	1.5	1.3	1.4	2.8	1.6	2.0
	3.1	1.8	1.7	1.3	1.0	1.0	1.9	1.5	1.6	2.8	1.6	2.7
	4.4	1.9	1.8	1.4	1.4	1.1	1.9	1.6	1.9	2.9	1.8	2.8
	5.0	2.1	1.9	1.6	1.5	1.2	2.1	1.8	2.0	4.2	1.9	2.9
	5.7	2.1	2.0	1.6	1.6	1.2	2.2	2.1	2.1	4.7	2.0	3.0
	5.7	2.3	2.0	1.7	2.0	1.2	2.4	2.1	2.1	5.3	2.0	3.1
	6.3	2.4	2.3	1.8	2.0	1.2	2.5	2.1	2.1	5.7	2.5	3.6
	7.0	2.6	2.3	1.9	2.6	1.2	2.5	2.1	2.2	5.7	2.8	3.6
	7.2	2.7	2.3	2.0	3.0	1.5	2.6	2.4	2.2	5.9	3.6	4.0
	10.8	2.8	2.5	2.1	3.3	1.6	2.7	2.4	2.2	6.0	3.7	4.0
	11.3	3.1	2.6	2.2	4.2	1.6	3.4	2.4	2.3	7.6	4.4	4.5
	11.8	3.6	2.7	2.3	5.2	1.8	3.5	2.4	2.4	7.8	4.5	4.9
	13.5	3.8	2.8	2.4	6.1	2.0	3.6	2.5	2.4	9.8	5.0	5.3
	14.2	3.9	3.0	2.5	6.7	2.2	3.6	2.5	2.6	10.2	5.3	5.8
	16.0	3.9	3.7	2.5	6.9	2.5	4.1	2.5	2.6	10.7	5.6	5.9
	18.5	4.0	3.7	2.7	12.2	2.5	4.1	2.7	2.8	11.0	5.7	7.4
	20.2	4.6	4.8	3.0	13.1	3.8	4.7	2.8	2.9	11.9	6.9	8.1
	26.4	5.1	6.0	3.1	15.8	8.8	4.9	3.2	3.2	13.1	7.8	8.9
	26.9	7.0	8.0	3.6	20.8	17.2	5.0	3.9	4.1	16.0	10.7	11.5
	27.1	11.2	13.2	3.8	22.2	19.4	5.1	4.1	4.3	17.8	15.8	12.3
	62.2	38.6	38.1	6.1	25.7	20.3	5.3	5.0	4.3	18.1	26.4	21.9
	68.8	82.5	56.6	7.8	304.5	30.5	6.0	11.0	4.6	60.0	27.9	26.8
MEDIAN	11.05	2.95	2.55	2.15	3.75	1.60	2.86	2.40	2.16	6.80	4.05	4.26
MEAN	15.68	8.20	6.99	2.53	19.36	5.28	3.26	2.78	2.52	10.15	6.31	6.56

NO.	LARGE SIZE PICTURES (15x15) 13	14	15	16	17	18	19	20	21	22	23	24
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	2.0	.9	.8	.9	.8	.9	.7	1.0	1.3	2.2	1.7	1.9
	3.4	1.5	1.2	1.4	1.2	.9	1.9	1.3	1.3	2.3	1.7	2.1
	4.1	1.6	1.3	1.5	1.2	1.0	2.1	1.3	1.5	2.5	2.0	2.2
	4.2	1.8	1.4	1.5	1.2	1.0	2.2	1.6	1.6	2.8	2.1	2.6
	4.5	2.0	1.4	1.5	1.7	1.1	2.4	1.6	1.6	3.1	2.2	2.7
	4.7	2.3	1.5	1.8	1.8	1.2	2.8	1.6	1.6	3.6	2.4	2.7
	5.7	2.4	1.5	1.8	2.0	1.2	3.2	1.8	1.7	4.3	2.6	2.7
	6.5	2.5	1.6	1.9	3.1	1.3	4.1	1.8	2.1	4.3	3.2	3.1
	7.4	2.7	1.6	2.0	4.2	1.4	4.1	1.9	2.2	4.4	3.4	3.3
	8.9	3.2	1.8	2.0	4.5	1.4	4.2	2.0	2.3	4.4	3.4	3.4
	9.4	3.2	1.9	2.2	4.7	1.5	4.4	2.2	2.4	6.1	3.6	3.4
	10.0	3.4	2.3	2.3	4.7	1.6	4.6	2.3	2.4	6.2	4.0	3.5
	12.4	3.5	2.3	2.3	5.5	1.6	4.8	2.4	2.5	7.1	4.4	3.5
	13.7	3.9	2.5	2.4	5.8	1.7	4.8	2.7	2.7	9.7	4.4	3.6
	14.2	3.9	2.5	2.4	5.9	1.7	4.9	2.8	3.1	9.8	4.9	3.8
	22.1	4.0	2.8	2.5	6.1	1.8	5.1	3.1	3.1	10.6	5.1	4.4
	31.6	4.0	3.5	2.6	7.1	1.9	5.1	3.3	3.1	10.8	6.5	5.7
	33.8	4.4	6.4	2.8	7.5	1.9	5.3	3.4	3.3	12.0	11.8	5.8
	34.6	4.6	6.4	2.8	9.3	2.0	6.1	4.0	3.8	12.6	13.7	6.9
	57.8	4.6	7.1	2.8	9.3	2.6	6.1	4.8	4.7	13.2	14.7	7.4
	58.7	4.7	8.5	3.2	10.0	3.4	6.4	5.7	5.2	14.1	16.0	7.4
	59.2	5.6	9.0	3.2	12.8	8.3	8.6	6.0	5.2	21.5	21.6	7.4
	60.3	9.3	10.9	3.5	18.2	15.0	10.0	17.0	5.3	40.2	45.6	23.6
	79.8	33.0	18.9	4.2	20.5	33.8	10.9	30.2	6.4	45.1	96.1	57.3
MEDIAN	11.20	3.45	[illegible]	2.30	5.11	1.60	4.69	2.35	2.46	6.65	4.19	3.50
MEAN	22.86	4.71	4.12	2.31	6.21	3.75	4.79	4.41	2.93	10.54	11.46	7.10

TABLE 5

RESPONSE TIME FOR TANK FARM TARGETS

NO.	SMALL SIZE PICTURES (5x5) 25	26	27	28	29	30	31	32	33	34	35	36
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	1.0	2.2	.9	1.5	1.6	1.7	1.3	.9	1.4	1.5	1.0	2.7
	1.2	2.6	3.5	1.7	1.8	2.3	3.6	1.0	1.5	1.7	1.3	3.2
	2.0	3.6	4.9	1.9	1.9	2.5	3.7	1.1	1.6	2.0	1.6	6.0
	2.0	4.6	6.0	2.0	2.4	2.9	3.9	1.4	1.7	2.2	1.9	7.8
	2.4	5.3	16.2	2.2	2.5	3.1	6.4	1.4	1.9	2.4	2.0	12.6
	2.5	6.1	16.7	2.5	2.9	3.4	6.5	1.5	2.0	2.6	2.1	14.8
	2.8	6.5	27.0	2.9	3.5	3.9	7.0	1.7	2.0	2.7	2.3	15.4
	2.8	7.1	30.2	3.0	3.5	4.0	8.1	1.8	2.4	2.8	2.3	15.5
	2.8	7.7	31.0	3.2	3.7	4.3	8.4	2.1	2.7	2.8	2.6	22.3
	2.9	7.9	32.0	3.2	3.7	4.5	8.5	2.2	5.0	4.0	2.6	25.9
	2.9	7.9	40.6	3.2	3.9	4.8	9.1	2.5	6.2	4.0	2.7	29.0
	3.1	12.8	42.8	3.8	4.0	4.9	9.5	2.5	6.8	4.0	2.7	32.0
	3.4	13.4	48.4	3.8	4.2	5.4	10.7	2.5	7.5	4.3	3.0	39.2
	3.8	13.5	53.0	4.0	4.3	6.4	11.2	2.6	8.0	4.7	3.1	39.3
	4.0	14.7	57.5	4.4	4.4	6.5	16.4	2.7	8.5	4.8	3.9	45.2
	4.0	15.5	66.5	4.6	4.5	7.3	16.8	2.8	8.9	5.0	4.5	60.9
	4.2	16.8	89.0	4.7	5.7	7.7	18.2	2.9	10.4	5.1	4.7	62.1
	4.3	17.3	98.1	5.2	5.8	8.3	22.9	3.0	11.0	5.2	5.3	65.4
	4.5	28.0	102.3	5.5	5.9	13.6	27.7	3.1	11.0	5.8	5.4	94.0
	4.7	34.0	108.6	5.9	7.2	13.7	30.5	3.3	12.5	6.1	6.8	96.9
	5.3	34.2	113.5	6.0	7.3	13.7	31.3	3.4	14.2	6.8	6.6	105.1
	7.1	39.1	130.6	7.6	9.2	17.9	43.9	3.9	14.9	10.1	7.8	147.3
	7.2	48.9	163.3	8.0	13.2	21.2	55.6	4.4	23.5	15.6	8.1	221.7
	11.4	50.7	178.2	8.8	24.9	48.5	69.9	29.3	28.5	35.5	11.5	252.2
MEDIAN	3.25	13.10	45.60	3.80	4.10	5.15	10.10	2.51	6.65	4.16	2.86	35.60
MEAN	3.86	16.68	61.77	4.15	5.50	8.85	17.96	3.50	8.00	5.90	3.99	59.02

NO.	MEDIUM SIZE PICTURES (10x10) 25	26	27	28	29	30	31	32	33	34	35	36
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	.9	2.7	.9	1.1	1.0	1.2	1.7	.8	1.2	1.1	1.1	3.6
	1.1	3.5	3.0	1.3	1.4	1.5	3.3	1.2	1.8	1.5	1.1	4.1
	1.6	3.5	3.4	1.4	1.4	1.6	4.5	1.4	1.9	1.6	1.3	6.9
	1.9	4.3	4.8	2.2	1.5	2.1	5.2	1.5	2.0	1.6	1.5	7.9
	2.0	4.5	5.9	2.5	1.6	2.4	5.6	1.5	2.1	2.2	1.8	8.2
	2.1	4.6	6.6	2.8	1.7	2.7	6.4	2.0	2.2	2.2	1.8	8.5
	2.2	4.6	6.7	2.9	2.0	2.8	6.4	2.0	2.4	2.3	1.9	9.1
	2.4	4.8	10.6	3.0	2.1	3.2	7.0	2.0	2.5	2.4	2.1	9.1
	2.8	6.4	10.9	3.1	2.3	4.0	7.7	2.1	2.5	3.1	2.4	10.0
	3.0	6.1	12.1	3.1	2.5	4.1	8.0	2.1	2.7	3.4	2.4	11.9
	3.0	7.9	20.4	3.3	2.7	4.3	8.6	2.1	2.8	3.4	2.6	14.6
	3.0	8.4	21.8	3.4	2.8	4.5	8.9	2.1	3.2	3.6	2.7	20.3
	3.2	8.8	23.9	4.0	3.0	5.1	9.0	2.2	3.5	4.0	2.8	21.1
	3.3	9.1	30.0	4.6	4.4	5.1	9.2	2.2	4.3	4.1	3.4	24.3
	3.8	9.5	53.0	5.5	4.5	6.5	9.4	2.2	5.5	4.6	3.9	44.0
	4.0	10.9	64.4	5.5	6.2	6.8	9.8	2.2	5.9	5.4	4.1	44.8
	4.3	17.8	85.2	6.3	6.3	7.1	13.0	2.4	5.9	5.5	4.2	53.6
	5.1	20.5	114.7	7.3	6.6	7.5	16.2	2.8	6.2	5.9	4.6	56.5
	5.4	22.8	141.4	7.9	6.7	8.3	16.6	2.9	6.2	6.3	4.9	56.7
	5.6	23.6	164.9	8.0	7.0	15.0	17.5	3.2	7.0	7.0	5.1	76.7
	6.3	25.5	235.9	9.0	8.3	18.6	21.7	4.4	8.0	7.9	5.9	80.8
	6.6	26.6	256.9	9.8	9.0	25.4	28.1	5.3	10.5	13.9	6.5	113.7
	7.8	35.4	276.4	11.3	15.8	59.3	41.3	5.4	12.5	21.8	6.7	162.2
	10.0	46.6	455.2	35.4	35.2	101.7	74.3	5.9	13.6	26.3	8.8	295.1
MEDIAN	3.10	8.60	22.85	3.70	2.90	4.80	8.95	2.15	3.35	3.80	2.75	20.70
MEAN	3.81	13.31	82.88	6.03	5.67	12.49	14.14	2.57	4.85	5.89	3.40	47.61

NO.	LARGE SIZE PICTURES (15x15) 25	26	27	28	29	30	31	32	33	34	35	36
REACTION OR RESPONSE TIMES ARRANGED IN ORDER OF INCREASING TIME	.9	2.2	2.2	1.0	1.4	2.1	1.7	.7	.9	.8	.7	1.3
	1.2	2.4	4.0	1.1	1.6	2.2	3.2	1.0	1.1	1.2	1.1	1.4
	1.4	2.8	4.2	1.2	1.8	2.4	4.8	1.1	1.4	1.3	1.3	1.8
	1.6	3.8	4.3	1.3	1.8	2.4	5.8	1.1	1.5	1.4	1.3	3.3
	2.1	5.0	4.9	1.6	1.9	2.6	6.4	1.2	1.7	1.7	2.0	5.4
	2.1	6.2	5.7	1.8	2.3	3.6	6.6	1.3	1.7	2.2	2.3	7.4
	2.1	7.0	6.1	1.8	2.6	3.7	7.5	1.4	1.9	2.3	2.4	8.0
	2.1	7.2	7.2	2.4	2.7	3.8	8.5	1.5	2.0	2.6	2.6	8.0
	2.3	8.5	8.3	2.6	2.8	4.0	10.0	1.8	2.1	2.9	2.9	8.2
	2.3	8.7	10.7	2.6	3.3	4.3	12.0	1.6	2.2	3.1	3.4	8.6
	2.4	10.3	15.5	2.8	3.3	4.4	14.0	1.8	2.2	3.2	3.7	8.9
	2.5	11.7	18.2	3.0	3.5	5.2	14.7	2.0	2.2	3.5	3.7	10.0
	2.8	20.4	18.5	3.5	3.6	6.3	15.8	2.2	2.6	3.9	4.3	11.6
	3.2	21.2	23.2	4.0	3.5	6.3	17.5	2.4	3.1	4.1	4.7	11.7
	3.2	22.1	25.9	5.0	3.8	5.7	19.9	2.4	3.1	4.9	4.8	16.2
	3.2	22.3	31.9	5.0	5.0	6.0	22.6	2.4	3.3	5.7	5.2	16.7
	3.5	24.1	37.2	5.2	5.3	6.6	26.2	2.6	3.5	6.2	5.8	17.6
	3.5	25.3	43.2	5.5	5.4	6.8	27.1	2.8	5.2	8.8	6.3	20.5
	4.7	29.0	45.4	5.8	6.5	8.5	27.4	2.9	5.4	10.1	6.5	24.9
	4.7	31.1	53.5	6.0	8.8	11.9	32.7	3.4	6.1	13.8	6.9	26.5
	6.0	38.3	66.3	6.3	9.6	14.3	50.4	3.7	6.2	16.6	7.0	33.2
	6.4	54.9	89.6	6.5	10.5	15.7	89.6	4.0	7.2	18.0	9.0	39.9
	7.2	69.5	151.2	7.4	12.5	22.2	172.8	5.1	16.8	29.4	12.0	59.2
	11.6	74.4	485.2	32.0	19.9	57.1	232.3	5.9	24.6	40.1	12.2	67.2
MEDIAN	2.65	16.25	18.35	3.25	3.49	5.24	15.25	2.10	2.41	3.70	4.00	10.80
MEAN	3.46	21.16	48.44	4.81	5.14	8.60	34.56	2.36	4.49	7.82	4.67	17.39

selection may be judged by inspection of the data in Tables 3, 4 and 5. They list, for each of the 108 pictures, the detection time or response time for the 24 observers that were tested on each picture. To construct these three tables, the original data was rearranged in order of increasing response time for each picture. It may be noted, from the tables, that every target in every one of the 108 pictures was found (detected) by at least one observer in not more than 2.2 seconds. Also, note that every target was found in less than 5 seconds by at least 3 observers. Every target was easy for some observers, though not necessarily the same observers for every picture.

Table 6 lists the median (or 50th percentile) reaction time for each picture. The median is that score above (and below) which half of all response times fall. The scores are each based on the detection time of 24 observers. At the bottom of the table the averages across all 12 pictures are listed. Note that airfields were the most quickly found type of target. Railroad yards were almost as easily found. Tank farms were more difficult. For example, the medians (or 50th percentiles) for the middle or medium sized pictures (the "M" row at the bottom of the table) were 3.72, 3.86 and 7.30 seconds, respectively for airfields, railroad yards and tank farms. Note that half of all observers found the average target of a given type in less than 7.4 seconds. The most difficult to find target was the tank farm in scene 27 for which the 50th percentile for the medium sized picture was 22.85 seconds. This is not long except in comparison to response times on some of the other pictures. However, 8 of the 24 observers tested on this

TABLE 6

MEDIAN RESPONSE TIMES AND RESPONSE TIME RANKS
FOR TARGETS ON SMALL, MEDIUM AND LARGE PICTURES

Picture Size	TYPE OF TARGET: Airfields No.	Time	Rank	Railroad Yards No.	Time	Rank	Tank Farms No.	Time	Rank
Small		3.60	1		8.10	1		3.25	3
Medium	1	4.20	2	13	11.05	2	25	3.10	2
Large		4.70	3		11.20	3		2.65	1
Small		1.16	1		3.10	2		13.10	2
Medium	2	1.40	3	14	2.95	1	26	8.60	1
Large		1.28	2		3.45	3		16.25	3
Small		6.59	1		3.87	3		45.60	3
Medium	3	8.00	2	15	2.55	2	27	22.85	2
Large		8.45	3		2.30	1		18.35	1
Small		7.02	2		1.95	1		3.80	3
Medium	4	5.75	1	16	2.15	2	28	3.70	2
Large		8.00	3		2.30	3		3.25	1
Small		9.00	3		3.70	2		4.10	3
Medium	5	8.20	2	17	3.75	1	29	2.90	1
Large		7.50	1		5.11	3		3.49	2
Small		1.65	1		1.45	1		5.15	2
Medium	6	1.70	2	18	1.60	2.5	30	4.80	1
Large		1.80	3		1.60	2.5		5.24	3
Small		1.19	1		3.40	2		10.10	2
Medium	7	1.34	3	19	2.65	1	31	8.95	1
Large		1.24	2		4.69	3		15.25	3
Small		1.35	1		1.91	1		2.51	3
Medium	8	1.51	2	20	2.40	3	32	2.15	2
Large		1.75	3		2.35	2		2.10	1
Small		1.31	2		2.01	1		6.65	3
Medium	9	1.44	3	21	2.16	2	33	3.35	2
Large		1.25	1		2.46	3		2.41	1
Small		2.49	3		5.90	1		4.16	3
Medium	10	2.00	1	22	6.80	3	34	3.80	2
Large		2.30	2		6.65	2		3.70	1
Small		5.05	1		5.20	3		2.86	2
Medium	11	6.40	2	23	4.05	1	35	2.75	1
Large		7.95	3		4.19	2		4.00	3
Small		2.21	2		3.65	2		35.60	3
Medium	12	2.64	3	24	4.26	3	36	20.70	2
Large		2.15	1		3.50	1		10.80	1
Average Over All Targets	S	3.54	1.58	S	3.69	1.67	S	11.41	2.67
	M	3.72	2.17	M	3.86	1.96	M	7.30	1.58
	L	4.03	2.25	L	4.15	2.38	L	7.29	1.75
Rank of Averages*	S		1	S		1	S		3
	M		2	M		2	M		2
	L		3	L		3	L		1

* Not rank of average ranks.

picture required more than one minute, which is long even on an absolute basis. One of the easiest targets, the airfield in picture 9, had a corresponding median of only 1.44 seconds.

It may be concluded that most of the 36 targets were found by most of the observers within a few seconds. In a word, most targets were easy. No target was very difficult for most observers. However, some targets were difficult for some observers.

II. The Effect of Target Size

The maximum target dimension of target images on all 36 medium sized pictures is given in Table 2. Each target image was also ranked from 1, the largest target, to 12, the smallest. For example, airfield 1, with a maximum image dimension of 22 millimeters, is ranked 10; it is the 10th from largest. Table 7, derived from Table 6, lists the ranks of response or detection time for the 12 individual targets. Here, ranks range from 1 (quickest) to 12 (slowest). Ranks are given for the 50th percentile (or median) rather than the arithmetic means, because the distributions of response time scores are not normal or even symmetrical distributions. The distributions are skewed due to some observers obtaining very long target detection times. Most response times "pile" up at the short time end of the distribution. The median, or 50th percentile score, is that detection time above which, and also below which, half of the scores lie. Tables 2 and 7, together, list a rank for target size and a rank for detection time for every target. These paired scores permit calculation of Spearman Rank Correlation Coefficients (r values) for the 12 pairs of data for each type

TABLE 7

RESPONSE TIME RANKS* OF TARGETS OF
EACH TYPE ON PICTURES OF EACH SIZE

Airfields				Railroad Yards				Tank Farms			
No.	Small	Medium	Large	No.	Small	Medium	Large	No.	Small	Medium	Large
1	8	8	8	13	12	12	12	25	3	4	3
2	1	2	3	14	5	7	6	26	10	9	11
3	10	11	12	15	9	4	2.5	27	12	12	12
4	11	9	11	16	3	2	2.5	28	4	6	4
5	12	12	9	17	8	8	10	29	5	3	5
6	5	5	5	18	1	1	1	30	7	8	8
7	2	1	1	19	6	6	9	31	9	10	10
8	4	4	4	20	2	5	4	32	1	1	1
9	3	3	2	21	4	3	5	33	8	5	2
10	7	6	7	22	11	11	11	34	6	7	6
11	9	10	10	23	10	9	8	35	2	2	7
12	6	7	6	24	7	10	7	36	11	11	9

*In each set of 12 targets of the same type, the one with the shortest response time is ranked 1, and the one wth the longest time is ranked 12. For example, airfield number 2 for the small pictures ranked 1 among the small airfield pictures, i.e., response to it was more rapid than response to any of the other eleven small pictures containing an airfield.

of target and picture size. The correlation coefficients are given in table 8. Note that the correlations between target size and response time were not statistically significant for any picture size for railroad yards. Most of the values for airfields were statistically significant. However, all r values were statistically significant for tank farms. Note that all r values in the table are positive, as expected; larger targets are responded to more quickly.

The effect of target size upon detection time may be summarized by noting that, for all picture sizes, correlation is appreciable and statistically significant for airfields and tank farms, but is small and not statistically significant for all picture sizes for railroad yards. For tank farm and airfield targets response time decreases to a statistically significant degree as target size increases.

III. The Effect of Picture Size on Response Time

The response time data of table 6 for the small, medium and large pictures are ranked from 1 to 3. A rank of 1 is assigned to the picture size with the shortest response time and 3 to the size with the longest response time. It is clear that sometimes response time is shortest for the target in the small picture, and sometimes response is quicker to targets in the medium or in the large pictures. The bottom of the table gives the average of the ranks and also the ranks of these averages. Note that airfields and railroad yards are found quickest in the small pictures. However, response to tank farms, the smallest type of target, was slowest by a large amount with the small pictures.

TABLE 8

CORRELATIONS+ BETWEEN TARGET SIZE AND RESPONSE TIME

Percentile++	Picture Size	Type of Target		
		Airfields	RR Yards	Tank Farms
50th (Median)	Small	.6340*	.4561	.7126**
	Medium	.7320**	.3754	.7443**
	Large	.7320**	.3814	.7478**
	Average+++	.6690*	.4035	.7866**
75th	Small	.4649	.4467	.7650**
	Medium	.5825**	.4112	.6808**
	Large	.6900*	.4140	.7337**
	Average	.6340*	.4456	.7866**

\+ Numbers in the table are all Spearman Rank Correlation Coefficients corrected for ties in ranks, and are correlations between target image size in millimeters and ranks on average response time for each target. Each one is based on 12 targets and all are positive, i.e., reaction to larger targets is quicker.

++ The 12 scores used for each type of target are ranks on the 50th (or 75th) percentile of the 24 reaction time scores for each target.

+++ The average response times used were obtained by averaging the response time median scores over the three picture sizes for each target and ranking these averages for the 12 targets of each type.

*,** Statistically significant at the .05 and .01 levels, respectively.

The ranks listed in table 6 for the three picture sizes were summed over the 12 pictures at each picture size. This yields the number of times that each rank occurred for each type of target. Table 9(A) lists the resulting frequencies of occurrences of ranks. It may be noted that numbers (or cell frequencies) are low in many cells, especially for a rank of 2.5 which represents ties in ranks. The data is in the form of frequencies or number of events, so that it may be used to perform chi square tests to see if picture size and rapidity of response are related. A limitation or rule that applies when performing such tests is that fewer than 20 percent of the cell frequencies should be less than 5, and none of them should be less than 1. From inspection of the table it is clear that cells will have to be combined, i.e., be collapsed, into fewer data categories to meet minimum required cell frequencies. When this was done for each type of target separately by combining the 2.5 rank data with other rank categories, some frequencies were still too low. Note that, at the bottom of table 9(A), when all types of targets are combined, frequencies in the 2.5 rank column are too low. Combining the 2.5 frequencies with other cell frequencies plus combining all target types is necessary. This is done in two different ways in tables 9(B) and 9(C). When chi square is calculated for these tables, neither value is statistically significant at the .05 level. It is concluded that the variation of response time to targets with variation in picture size has not been proven, i.e., it must be regarded as a chance result or artifact.

It appears reasonable to expect that those targets that are the easiest to find on any one si e of display, will be the easiest, or nearly so, on

TABLE 9

NUMBER OF TIMES THAT EACH RANK OCCURRED
FOR EACH OF THE THREE PICTURE SIZES

(A) FREQUENCIES AT ALL FOUR RANKS

Target Type	Picture Size	Rank on Response Time*			
		1	2	2.5	3
Airfields	Small	7	3	0	2
	Medium	2	6	0	4
	Large	3	3	0	6
Rail Road Yards	Small	6	4	0	2
	Medium	4	4	1	3
	Large	2	3	1	6
Tank Farms	Small	0	4	0	8
	Medium	5	7	0	0
	Large	7	1	0	4
All Types Combined	Small	13	11	0	12
	Medium	11	17	1	7
	Large	12	7	1	16

*Data is for the median (or 50th percentile) reaction times. The data in this table is compiled from Table 6.

(B) ALL TARGET TYPES COMBINED;
FREQUENCIES AT RANKS 2 and 2.5 COMBINED

Picture Size	Rank on Response Time			Chi Square	Probability, P
	1	2 + 2.5	3		
Small	13	11	12		P < .10
Medium	11	18	7	7.92	Not Statistically
Large	12	8	16		Significant

(C) ALL TARGET TYPES COMBINED;
FREQUENCIES AT 2.5 and 3 COMBINED

Picture Size	Rank on Response Time			Chi Square	Probability, P
	1	2	2.5 + 3		
Small	13	11	12		P < .10
Medium	11	17	8	7.81	Not Statistically
Large	12	7	17		Significant

TABLE 10

CORRELATIONS BETWEEN RESPONSE TIMES
FOR TARGETS ON DISPLAYS OF DIFFERENT SIZES

Correlated Picture-Sizes*	Rank Correlation Coefficients		
	Airfields	Railroads Yards	Tank Farms
Small-Medium	.9650	.8811	.9231
Small-Large	.9282	.7706	.7622
Medium-Large	.9317	.9002	.8182

* Each correlation coefficient is between the ranks on target detection times of 12 targets. The ranks are each based on the median of 24 response times on each target. All nine coefficients are statistically significant at the .01 level.

another size of display. Also, it appears likely that difficult targets will retain much of their difficulty on different sizes of displays. One would expect that the correlations between detection times for targets would be higher for targets on displays that differ widely in size. Table 10 gives the correlation coefficients, permitting examination of this conjecture. The tabled values support the expectation; the lowest correlation coefficient for each type of target is the one in the small-large display size row of the table. For all 3 types of targets, then, predictability (or r) of response time is higher between displays that are adjacent in size than between displays that differ considerably in size.

IV. Summary and Conclusions for the Experiment

Display size was varied in a study that used side-looking airborne radar as the sensor and pictures on transparent film on a light box as the display. There were 36 ground scenes, each containing one unbriefed target. The targets were airfields, railroad yards and tank farms. Targets were preselected to eliminate any that appeared to be quite difficult to find. All 36 scenes were prepared in three sizes of film, for a total of 108 pictures. The smallest target on the smallest display subtended, at the observer's eye at a 12 inch viewing distance, over 30 minutes of arc. Thus, all target images were adequate in size for easy visual examination.

Three picture or display sizes were used: small (5" x 5"), medium (10" x 10") and large (15" x 15"). These sizes cover the range of sizes that are practical for aircraft displays of radar imagery. Before each picture was presented to the observer he was told what type of target was on it. Seventy-two SAC and TAC Radar Navigators were tested on the 108 pictures. All observers searched for all targets, but no target was presented to any observer more than once: he saw it in only one picture size. Thus, each observer saw one third of the pictures, and every target in every size of display yielded 24 target detection time or reaction time scores.

Most targets were found by most observers within a few seconds: no target was difficult for most observers. However, some targets were difficult for some observers. Only for airfield and tank farm targets did response time decrease, to a statistically significant degree, as target size (not picture or display size) increased. Individual targets maintained, to a high degree, their average response time relative to other targets of the same type.

Even with 24 detection times for each target in each picture size, average response time was sometimes quickest for the target in the small picture, and was sometimes quickest for targets in the medium or the large picture. On the average, airfield and railroad yard targets were found quickest in the small pictures and slowest in the large pictures. However, response to tank farms was slowest with small pictures. However, by statistical test, response time did not vary significantly with picture size, i.e., the result must be regarded as due to chance. No one size was superior. What results would be found with briefed targets, difficult-to-detect targets, dynamic imagery, different types of targets, different sensors, different displayed resolution, etc. is unknown. It is clear that more research is required on optimum display size for different values of many parameters.

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